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MODELLING FOR SIMULTANEOUS SELECTION OF
OPTIMAL BUS ROUTES AND THEIR FREQUENCIES—
A CASE STUDY FOR AHMEDABAD

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

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by

UMRIGAR FAROKH S.

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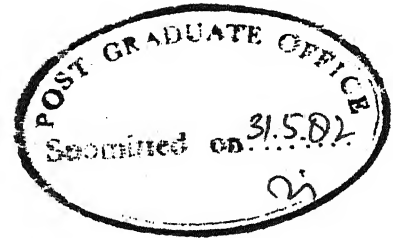
DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
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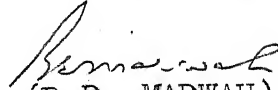
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CERTIFICATE

Certified that the work on 'Modelling for Simultaneous Selection of Optimal Bus Routes and Their Frequencies - A Case Study for Ahmedabad', by Umrigar Farokh S. has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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ACKNOWLEDGEMENTS

Author takes this opportunity to express a deep sense of gratitude and appreciation towards Dr. B.R. Marwah, for his expert guidance, encouragement and inspiration throughout the development of the thesis.

Author thanks all his friends and colleagues in the department and outside, particularly Shri Dinesh Dave, Shri M.K. Vora, Capt. C.P. Gupta, Shri S.B. Patnaik, Sudhakar and Kulkarni, for their unstinted cooperation and help whenever and wherever needed.

Author owes a word of thanks to Mr. G.S. Trivedi for his efficient typing.

Umrigar, F.S.

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LIST OF NOTATIONS

AVERSP	-	Average speed of the bus (Kmph).
(BUSTRP) _r	-	Number of bus trips for a route r.
CAP	-	Maximum number of passenger that can be accomodated in a bus.
DIST(i, j)	-	Internodal distance between the nodes i and j.
FLOW(i, j)	-	Flow on a link connecting the nodes i and j.
(FREQ) _r	-	Frequency on route r.
(INCOME) _i	-	Daily average traffic income in paise for a route i.
JFLOW(i, j)	-	Flow of passengers between the O-D pair i-j.
KMCOST	-	Operating cost of a vehicle (60 seat capacity) per vehicle kilometre.
(LF) _i	-	Average load factor for route i.
(LKFLOW) _i	-	Flow of passengers in unit time on link i.
(LKFLOW*) _i	-	Flow obtained by using T_i^* as the link time.
(LNGTH) _i	-	Length of the link i.
(LOT) _r	-	Lay over time at the destination of a route r.
(LT) _i	-	Total link time of the i^{th} link.
(MAXF) _i	-	Maximum fare in paise for a route i.
(MAXFRE) _r	-	Maximum frequency of route r.
(MAXTFL) _p	-	Maximum value of the turning flow for the p^{th} turning movement.

- M1 - Number of inequality constraints in the
LP formulation.
- M2 - Number of equality constraints in the
LP formulation.
- NLINKS - Number of links in a route.
- (NOBUS)_i - Number of bus trips to be made in a unit
time on a link i.
- NONODS - Number of nodes (stops) in a route.
- (NOTRAN)_{pr} - Number of transfers saved for p_{\dots}^{th} turning
flow.
- (NOTRN)_p - Number of transfers saved for p_{\dots}^{th} turning
movement.
- NR - Number of routes in a network.
- (NR)_k - Number of interested routes touching the
stop k of a route.
- (NUMP)_r - Number of passengers served by a bus trip
of route r in one direction.
- OPF - Operating fleet size for the bus transit
network.
- OT - Operating time i.e. the number of hours
for which the bus service is provided in
a day.
- (PROB)_k - Probability of a passenger to get down at the
stop k of a route.

- $(RT)_{ir}$ - Riding time on link i traversed by route r .
- $(RTIME)_r$ - Round trip time on a route r .
- $SD(i, j)$ - Shortest distance between the origin i and destination j .
- $(ST)_j$ - Service time (dwelling time) at the j^{th} stop of a route.
- T_i - Revised time on link i considering the riding time of passenger and the vehicle time for the first iteration.
- T_i^* - Revised time on link i considering the riding time of passenger and the vehicle time for the subsequent iterations.
- TLT - Total time of the network.
- $(TRIPS)_i$ - Number of scheduled bus trips in a day for route i .
- $(TRIPSG)_i$ - Number of trips generated at the stop i .
- $(TRL)_r$ - Total route length of route r in Kms.
- $(TRT)_r$ - Total riding time on route r .
- $(TST)_r$ - Total service time in one direction for route r .
- $(TT)_r$ - Total travel time in one direction for route r .
- TTER - Number of turning flows along a route.
- $(TTRAN)_r$ - Total number of transfers saved by a route r .

- (TURNFL)_{lk} - Number of passengers going directly from link l to link k or vice versa in a day.
- TTF - Total number turning flows (movements) in a network.
- VT - Value of riding time in Rs./hr.
- (VOLP1)_i - Average link volume on route i by load factor criterion.
- (VOLP2)_i - Average link volume on route i by maximum fare criterion.
- W - Weight for the value of a vehicle time compared to a riding time of a passenger.
- Z - The objective function for the LP problem.
- Z₁ - The objective function for the problem of concentration of flow.

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SYNOPSIS

A few major limitations of the past research in the area of routing and scheduling of the bus transit system are: (i) the generation of routes and scheduling of vehicle in the network is done sequentially, (ii) evaluation of alternative paths of a route is carried out independent of the already accepted routes for the network.

In this study, an attempt has been made to develop a method such that the selection of the routes and the assignment of frequencies is done simultaneously for the bus transit system. The method has been developed in four stages: (i) to generate a trip distribution matrix, (ii) to concentrate the flow of passengers on the road network such that the sum of passenger-riding-time-cost and operation cost is minimized, (iii) to generate a large set of all possible routes that satisfy the various constraints, (iv) to select routes and their frequencies so that number of transfers saved on the network is maximized. Heuristics have been used for the concentration of the flow and generation of the routes while Linear Programming (LP) has been used to select routes and their frequencies.

A method has been suggested to estimate trip distribution matrix by using generally available traffic data of the existing routes for the city bus network.

The flow of passengers on the various links of the network is concentrated such that the sum of passenger-riding-time-cost and operation cost of the vehicles is minimized. An heuristic algorithm has been developed for concentrating the flow. The relationship between the number of bus trips and the flow of passengers on a link has also been derived. The starting network consists of all the links where vehicles could possibly travel. Passenger flows have been systematically concentrated by eliminating the links, in stages such that the total cost is minimized.

For a given desired travel matrix, a large set of all possible routes between different O-D pairs is generated using an heuristic procedure. The generated routes satisfy the practical constraints of length and the deviation from the shortest path.

The total number of transfers saved on a route is determined based on the size of the turning movements along the route and the estimated number of bus trips on the links. For a given operating fleet size the

simultaneous selection of routes and their frequencies is done by Linear Programming such that the total number of transfers saved on the network is maximized.

Ahmedabad city has been chosen for the case study for structuring of the bus transit network. The optimal set of routes and their frequencies have been estimated for three operating fleet sizes.

1 INTRODUCTION

1.1 General

The ability of cities to expand in size depends heavily upon the available means of public transportation. Originally, travel on foot, or by crude land-based means, severely limited the ability of cities to develop. With the industrial revolution, public transportation systems that would move large numbers of people came into existence, due to the rapid growth of cities and the separation of home and work place. So, urbanization is a worldwide phenomenon. The urban population is growing at a rate of 4 to 7 percent a year. In some cities of India, the growth is as high as 12 percent.

The two most important modes of public transportation particularly for the cities of the developing country like India are bus transit system and commuter rail system. Each mode has a role to play in furnishing transit services, and the task of the engineer and the planner is to integrate each into a coherent system of public transportation.

The bus transit is the most prevalent mode and carries over 70 percent of all transit travel. Its inherent advantage is the ability to be routed along any street or highway, and for this reason buses serve many land-use

densities and urban configurations. As the 'work-horse' of public transit, the bus lacks glamour, but its attributes of reliability, availability, flexibility and economy indicate that it will remain as the most popular mode of public transportation for years to come.

The urban transportation system is comprised of an intricate and complex arrangement of various public transportation modes, and there are many elements and factors that should be considered in assuring that each mode operates harmoniously to produce a high level of transit service. As stated earlier, 70 percent of all transit travel is taken by bus system, it is imperative to plan and operate the existing bus transit systems in most effective way with the available resources.

1.2 Statement of the Problem

In spite of the advantages of bus transit system, bus route configurations in most cities have virtually remained unchanged. Only in the recent years the importance of a large-scale re-evaluation of bus routes has been realized. One of the main reasons for the inefficiency of the bus transit system is the lack of systematic approach in designing the transit network.

The problems that are normally encountered by a bus transport management are economy in operation, reliable and adequate level of service to the users. To solve these problems it is necessary to investigate the following:

- (i) Structuring of the routes in order to meet the demand in an effective manner.
- (ii) Determination of the minimum fleet size for a specified level of service for the system.
- (iii) Determination of the schedules to minimize the overall system costs.

Traditionally, bus networks were designed on the basis of the planners' own experience. In addition, other approaches that have been attempted are mathematical programming, heuristic searching and simulation. The approach of formulating the network design as a problem of mathematical programming has not been capable of dealing with networks of realistic size due to the limitations of computer capacity. Most of the heuristic searching approaches, on the other hand, also fall short of becoming a comprehensive framework for network design due to the fact that they are originally developed primarily as frameworks for route selection rather than for network development. Simulation of the transit system, though a powerful tool, has been restricted mostly to

individual routes or small size transit networks. Following section highlights some of the pertinent research in this direction.

1.3 Review of Literature

Lampkin and Saalmans (1967) analyzed the routing and scheduling of a city bus service by first designing a route network and then allocate frequencies (interarrival times) to these routes. The major component of the operating cost was taken as the cost of crews, so minimizing total travel time subject to a given crew strength is equivalent to minimizing total travel time subject to a fixed level of profit or loss.

The total travel time for the network was calculated, taking the routes to be fixed for the three cases:

- (i) When the time to walk is greater than the bus time plus interarrival time of most frequent route joining the nodes. If only one route joins the origin node and destination node, then average journey time is the sum of bus time and half of the interarrival time. If more than one bus routes join terminating nodes, the proportion of passengers using the different routes were found out and the average bus time was calculated. The average journey time was taken as the sum of the average waiting time

and average bus time.

- (ii) The second case, they considered was that passenger waits if the sum of the bus journey time and time to the next bus is less than or equal to walking time for his destination, otherwise he walks.
- (iii) For the third case, they considered only the walking times by different route alternatives and the minimum average journey time was found out.

The objective of minimizing the total travel time was achieved by a modified random search procedure, in which an initial guessed solution started the procedure and thereafter new value of frequencies were produced by random perturbations from the best frequencies found to date.

An heuristic algorithm was developed for structuring a route network. It consists of producing an initial skeleton route of four nodes and then inserting nodes one by one until a complete route is obtained. The demand met by this route was eliminated from the travel matrix. The other routes were obtained for all significant demands left over. The best node to insert in a given gap in a skeleton is a node which improves the value of the objective function, consisting of maximizing passenger-kilometres

with penalty for excessive meandering.

The limitations of their study are that their approach does not consider the previously accepted routes while generating the subsequent routes so the effect of the interaction of various routes is not taken into consideration.

Hsu and Surti (1975) gave a method of optimal bus network design based on nodal demands. Bus routes were first classified into several categories (i.e. corridor, activity, transfer, residential) each having a different developmental priority. After the number of bus routes to be included in each stage was determined, the origins and the destinations of potential routes were identified. Optimal alinement connecting the route origin and destination was subsequently located. The separate consideration of the route origin-destination and route alinement was made possible by the relationship between the route performance and the attractiveness of route origin and destination. Their method differs from that of Lampkin and Saalmans (1967) in the criterion for evaluating route alternatives. Their approach of maximizing passenger per kilometer over the route alternatives seems better than maximizing passenger-kilometers used by Lampkin and Saalmans. The latter approach will give the same priority to the

alternative with longer length and less passengers as given to the one with shorter length and more passengers.

Last and Leak (1976) gave a computer based model ('TRANSEPT') that evaluates bus networks, i.e. it predicts the trip makers who are expected on a network, works out the implications of those trip-makers for each route, and for the network as a whole. They carried out a review of the bus system then in operation by performing the following tasks:

- (i) Structuring the bus network so as to identify potential journeys within it.
- (ii) Predicting the number of trips which will use these potential journeys.
- (iii) Implications of these trip-makers (patronage) for bus loadings and subsequent evaluations.

This study provided the insight into operation of network at four levels, viz. operational, financial, user and modal split.

Dhingra (1980) designed the routing and scheduling of a city bus service by considering the following tasks:

- (a) to design the optimum route network for a given travel demand;

- (b) to design the optimum fleet size;
- (c) to study the effect of variation in total fleet size on waiting time, load factors and other performance measures;
- (d) to design the optimum schedule.

An heuristic approach was taken to design the route network. It consists of following steps:

- (i) Given the O - D trip matrix the major generators were identified.
- (ii) The routes between the major traffic generators were identified using shortest path trees.
- (iii) The travel demand met at the nodes covered by the above routes was determined.
- (iv) If the demand at the uncovered nodes is significant, additional shortest routes were identified.
- (v) He assumed that the additional distance of any route alternative thus generated should not be greater than two-third of the original shortest routes.

He evaluated the route alternatives on the following three criteria:

- (a) Passenger-kilometers criterion maximizes the passenger-kilometers over all the route alternatives.

This criterion does not discern the difference between a longer route with low passenger density and a shorter route with high passenger density.

- (b) Average link density criterion maximizes the average link density over the route alternatives. This criterion favours the alternative with more passenger density and the shorter length of the route.
- (c) Route utilization coefficient criterion maximizes the route utilization coefficient over route alternatives.

After fixing the routes, he found out the fleet size and designed a schedule to meet the travel demand in an optimal way, using simulation model as a tool. This simulation model simulates at a microlevel, the flow of passengers and vehicles in a given network. The salient features of the simulation model are as follows:

- (a) It simultaneously simulates the flow of passengers on all the nodes of the network and the movement of the vehicles on all the routes thereby taking into account the interaction effects of overlapping, crossing, merging and diverging routes.
- (b) Input to the model is average passenger arriving volume, their probability distribution, relationships

for the boarding, alighting and booking times of passengers at each station, internodal distances, running times and capacities of the vehicles. In order to incorporate the interaction of the overlapping routes in the network, the station scanning technique is used.

- (c) The output from the simulation model consists of three parts; the output for each of the stations, the routes and the network. At a station, the output related to passengers consists of the waiting time, queue length and service times. For a route, the simulation results are in the form trip times, vacancy/load factors, waiting times, number of passengers processed, the route speed and passenger-kilometers operated. For the network, the results are in the form of average queue length, the passengers processed for a period, the vehicle kilometers operated, waiting time and load factor.

The limitations of Dhingra's study are as follows:

- (i) Routes are designed based on travel demand and are assumed to be independent of schedules.
- (ii) No studies have been conducted to establish delay cost per hour. It has been calculated assuming the average income and working hours per month of the bus transit users.

- (iii) The use of a vehicle over multiple routes is not covered.
- (iv) Crew rostering and runcutting operations have not been covered.
- (v) The problem does not cover the multiobjective analysis but two conflicting costs of delay and operation are considered.

The studies by Lampkin and Saalmans (1967) and Hsu and Surti (1975) attempt towards total network design. But none of the above models consider the previously accepted routes.

1.4 Objectives of the Study

The management of the public transportation company has got limited variables to play with, due to political and social influence. In India, the normal situation is that the fare is not decided strictly in accordance with the operator cost but it is a compromise between operators' cost and the passengers' ability to pay. Within these limits the management may choose routes and frequencies freely. So, the objective should be to maximize social utility with the restrictions on operating cost and minimum travel standard.

The literature (Section 1.3) for the various models of bus transit planning indicate that the

generation of routes and the scheduling of vehicles in the network is done sequentially. The routes are first generated, one at a time based on the given desired travel matrix. A route is evaluated independent of the routes already accepted for the network. Evaluation by such an approach does not fully consider the interactions in the transit routes. The scheduling of the vehicles on the routes is done after all the routes in the network have been fixed.

The objective of the study is to develop a method such that the selection of the routes and the assignment of the frequencies is done simultaneously for the bus transit system. The method should be applicable to the real world large size bus networks. The method suggested is a combination of heuristic search and programming models. The method first considers all the links on which the vehicle possibly could travel. The flow of passengers is then systematically concentrated by eliminating links so that the total cost (i.e. passenger-riding-time-cost + operation cost) is minimized. A large set of possible routes, which satisfies the various requirements, is generated. The selection of the routes and their frequencies is done using the programming model so that the number of transfers saved on the network is maximized.

1.5 The Extent and Scope of the Study

This study aims at the structuring of bus transit network in which selection of routes and assignment of frequencies is done simultaneously for the fixed O - D matrix. The approach suggested in the study uses heuristic search and mathematical programming models. The salient features of this study are:

- (i) Ahmedabad city has been chosen for the case study and the system of models developed have been used for structuring of the transit network and assignment of frequencies to the routes.
- (ii) Due to nonavailability of the bus trip distribution matrix for the cities in India, a method has been suggested to generate the same by using generally available traffic data of the existing routes in the network.
- (iii) The computer programmes for the system of models have been developed and can be applied to any transit network.

The problem under investigation is limited due to constraints on the availability of data and time. Some of the limitations are as follows:

- (a) Structuring of routes and the assignment of frequencies is done for a given desired trip

matrix and does not evaluate the stochastic variations in the travel demand.

- (b) The frequencies (number of bus trips) are assigned for the full day. The variations of the headways over the day have not been investigated.
- (c) Operator cost and passenger-riding-time-cost have been considered in terms of time by estimating their weights.

1.6 Organisation of the Report

The study is reported in the following sequence:

- (i) The models for generating a fixed O - D matrix, concentration of passenger flow, systematic route generation and selection of routes and their frequencies, are developed (Chapter 2) .
- (ii) Description about the case, traffic data requirements and analysis of data are given. Experiments for limited range (670 to 790) of fleet size are done to study its effect on the optimal number of routes and the number of transfers saved. The optimal set of routes with their frequencies for the case problem is presented. The results are analyzed to establish the relationships between the variables of interest. The relationships between the fleet

size and number of transfers saved; fleet size and optimal number of routes and fleet size and average route length are presented (Chapter 3).

- (iii) Study is summarized, conclusions are drawn and suggestions are made for the future investigation (Chapter 4).

2 DEVELOPMENT OF THE MODEL

2.1 Introduction

Today's transit planning, particularly in developing countries like India, is inefficient due to the lack of systematic approach in designing the networks. Different approaches fail to provide planners with a handy and powerful tool in the following aspects: the experience based approach is basically an intuitive approach and cannot promise any solution in the optimal sense; the mathematical programming approach is theoretically rigorous but fails to handle any network of realistic size; heuristic search algorithms are designed primarily for the microscopic problem of route-selection rather than the macroscopic task of network design. In addition, simulation of the transit system though a powerful tool has been restricted mostly to individual routes or small size transit networks.

Theoretically, it can be seen that the routing and scheduling processes for a bus transit network interact and a global objective function should be formulated in devising solutions for the problems. However, in actual practice, it is not possible to formulate the problem structure in this way. Usually this class of problems can be tackled recursively by dividing the original problem

into problems involving subsystems which can be made tractable.

The problem of automatically generating a good urban route system has been treated by a few authors as reviewed in Chapter 1. A common method is to sequentially generate and evaluate routes without seriously reconsidering previously accepted routes. In spite of this, only relatively small systems have been analyzed probably due to excessive computation time. The purpose of this study is to propose a method such that the selection of the routes and the assignment of the frequencies is done simultaneously for the bus transit system. The method should be applicable to the real world large size bus networks and involves lesser computation time. The method suggested is a combination of heuristic search and programming models.

2.2 Overview of the Model

The proposed method consists of the following steps:

- (i) Generate a fixed desire travel matrix (i.e. a matrix that gives a good idea of the potential demand in every origin-destination relation).
- (ii) Generate a network which consists of all the links on which the vehicle possibly could travel.

- (iii) The flow of passengers is then systematically concentrated by eliminating links so that the total cost (i.e. riding time cost + operation cost) is minimized .
- (iv) A large set of possible routes, which satisfy the various requirements, are generated.
- (v) The total number of turning movements for the network are identified and the number of transfers saved for each turning flow along the route and for all the routes, are found out.
- (vi) The selection of the routes and their frequencies is done using the Linear Programming (LP) model so that the number of transfers saved on the network is maximized.

2.3 Origin - Destination Matrix

The model needs the volume of the distribution of trips between various nodes. In absence of origin-destination data for the trip distribution, the following procedure can be applied to the existing bus route network for obtaining the desired travel matrix. The steps in the procedure are as follows:

- (i) Average link volume on each route during the day is obtained from load factor and maximum fare criteria.

- (ii) Each stop on a route is assigned a weight depending upon the importance of the stop quantitatively measured in terms of number of routes touching the stop. These weights are used to define the probability of trip generation on each stop of a route.
- (iii) The generated trips at a stop are then distributed to other stops of the route using the relative weights of the different stops.
- (iv) The trip-distribution matrix for the network is obtained by combining the distribution of all the routes. Fig. 2.1 shows the procedure for generating O - D matrix.

2.4 Riding Time on Links

For the concentration of link flows on the network, the riding times on various links need to be estimated. Generally, travel time of the bus on a route is available. The total riding time of a route r i.e. $(TRT)_r$ is estimated using the following relationship:

$$(TRT)_r = (TT)_r - (TST)_r \quad (2.1)$$

where

$$(TST)_r = \sum_{j=1}^{NONODS-1} (ST)_j \quad (2.2)$$

where

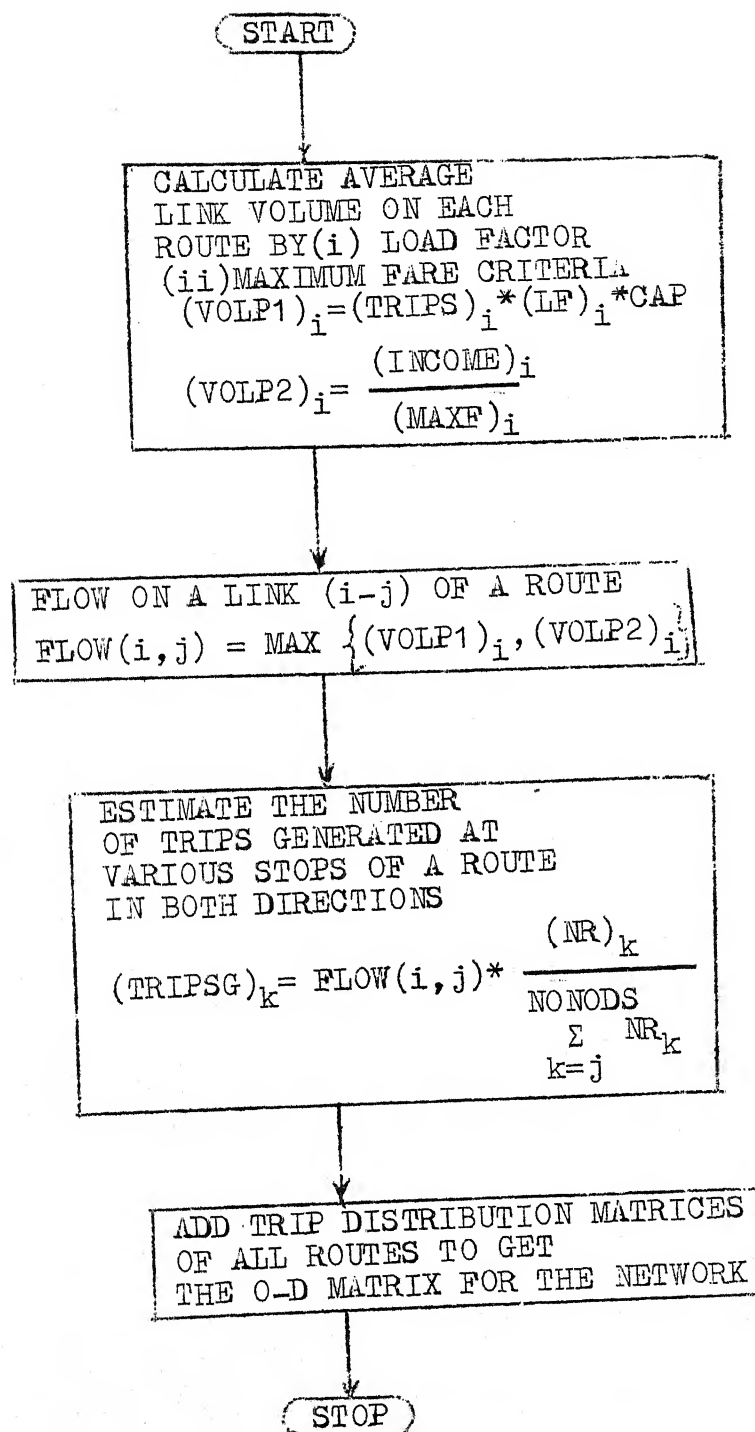


FIG. 2.1 : PROCEDURE FOR GENERATING O-D MATRIX

- $(TRT)_r$ = Total riding time on route r
 $(TT)_r$ = Total travel time in one direction for route r
 $(TST)_r$ = Total service time in one direction for route r
 $(ST)_j$ = Service time at the j^{th} stop of the route.

After estimating the total service time for a route in one direction, the total riding time $(TRT)_r$ is calculated by Eqn. 2.1. The riding time on link i traversed by route r is calculated by the following relation:

$$(RT)_{ir} = (TRT)_r * \frac{(LNGTH)_i}{NLINKS \sum_{i=1} (LNGTH)_i} \quad (2.3)$$

where

- $(RT)_{ir}$ = Riding time on link i traversed by route r .
 $(LNGTH)_i$ = Length of link i .
 $NLINKS$ = Number of links in a route.

If there is a variation in riding time obtained for links served by the number of routes, then the average value of the riding time is used.

2.5 Preparation of the Road Network

For the concentration of flow, a starting network, consisting of all the links where vehicles could possibly

travel is needed. The length of the link and the riding time on the link can be found out from existing route characteristics like length, travel time, and service time for the route. The riding time on the links which are added to the existing route network can be found out by considering the average speed of the bus obtained from the data of the existing system.

2.6 Model for Concentration of Passenger Flow

2.6.1 General

The model estimates where the passengers are expected to travel in the optimal route system. From the passengers point of view, they would like to travel by their shortest paths, which would imply a very dispersed route network with low vehicle utilization and many vehicle hours. On the other extreme if the links, on which there is negligible or less flow, are deleted then the passengers will have to make substantial detours from their shortest paths, with increased riding time for the passengers. To get a reasonable compromise between these two extremes the sum of operation cost and passenger riding time cost can be minimized for a fixed desired O - D matrix.

Let RT_i be the riding time on link i and $((LKFLOW)_i)$ is the passenger flow in unit time on link i

then the total riding time for all the passengers is $\sum_i (RT_i) ((LKFLOW)_i)$ and the total vehicle time for the network is $\sum_i (RT_i)(NOBUS)_i$ where $(NOBUS)_i$ is the number of bus trips to be made in a unit time on a link i . The objective function is: minimize (passenger-riding-time cost + operation cost) i.e.

Minimize

$$Z_1 = (\sum_i (RT_i)(LKFLOW)_i) + \sum_i RT_i (NOBUS)_i . W \quad (2.4)$$

subject to all demand of travel matrix is satisfied.

where

W = value of vehicle time compared to riding time of passenger.

The parameters $(NOBUS)_i$ and W are to be estimated using the available data of the bus transit system.

Estimation of Parameters:

(a) Number of bus trips on a link

The number of trips to be made in a unit time on a link i.e. $((NOBUS)_i)$ depends upon the passenger flow on that link i.e. $((LKFLOW)_i)$. Some studies (Scott, 1969; Rea, 1971) indicate that $(NOBUS)_i$ is directly proportional to the square root of passengers on a link. If such relationship for a particular city or country is not available, then using the data of average link flow and

number of bus trips, regression analysis can be carried out to get the following relationship:

$$(\text{NOBUS})_i = A((\text{LKFLOW})_i)^B \quad (2.5)$$

where A and B are the constants to be estimated.

(b) Value of vehicle time compared to riding time of passengers (W)

W is calculated using the following relationship:

$$W = (\text{BUSKMH}) * (\text{KMCOST})/(\text{VT}) \quad (2.6)$$

where

BUSKMH = Kilometers travelled by a bus in one hour.

KMCOST = Operating cost of a vehicle(bus) per bus kilometer.

VT = Value of riding time of the passenger.

The operating cost of a vehicle per bus kilometer is found out by taking into consideration the heads like salary and allowances, fuel and lubricants, repairs and spare parts, overheads, depreciation and head quarter charges.

The value of riding time of the passenger can be found out by assuming an average income of captive user and value for unit time is calculated.

The value of BUSKMH can be obtained from the existing data of speeds of the bus on various sections of

the networks. Generally the speed in the central business district area is comparatively less than the outlying and peripheral areas of the city. So the average speed is taken from the existing speeds data.

2.6.2 Analysis of the Objective Function

The objective function defined in Eqn. 2.4 can be written as follows by substituting $((\text{NOBUS}))_i = A(\text{LKFLOW})_i^B$

$$\begin{aligned} \text{Minimize } Z_1 &= \sum_i (\text{RT}_i)(\text{LKFLOW})_i + \sum_i (\text{RT}_i)A \cdot (\text{LKFLOW})_i^B \cdot W \\ Z_1 &= \sum_i (\text{LKFLOW})_i \left[(\text{RT}_i) \left(1 + \frac{(W) \cdot (A)}{(\text{LKFLOW})_i^{1-B}} \right) \right] \quad (2.7) \\ &= \sum_i (\text{LKFLOW})_i \cdot T_i \end{aligned}$$

where

$$T_i = (\text{RT}_i) \left(1 + \frac{(W) \cdot (A)}{(\text{LKFLOW})_i^{1-B}} \right) \quad (2.8)$$

The objective function Z_1 (Eqn. 2.4) is nonlinear. When a network consists of all the possible links where vehicles could travel, the passengers will travel along their shortest paths with the result that the first component of the equation related to passengers' cost namely $\sum_i (\text{RT}_i)(\text{LKFLOW})_i$ will be minimum, but the second component related to the operating cost of the vehicle namely $\sum_i (\text{RT}_i)(\text{LKFLOW})_i^B (A) \cdot (W)$ will be more. So to get a compromise between these two

components, the sum of the passenger-riding-time-cost and the operating cost should be minimized.

When analyzing vehicular-traffic, the increase in total cost on a link, due to one more vehicle is an increasing function as the flow increases, the total riding time on the link also increases. In the bus transit system (Fig. 2.2) as the flow increases, the change in cost as related to passenger flows on a link i.e. $(PTCOST)_i$ reduces for a unit change of flow i.e. $(LKFLOW)_i$. So by increasing or concentrating the flow on link i, the total cost can be reduced.

To achieve the objective of minimizing the total cost (Eqn. 2.7), various alternative networks of links are evaluated and that network of links is selected which gives the minimum total cost. In case where it is difficult to estimate the value of time, then time values can be directly taken as cost units.

The starting network consists of all the links on which vehicle possibly could travel. The problem of concentrating the flows can then be seen as one of eliminating the links from this finemeshed network. The other way of looking at a problem is to reduce flow concentration by adding possible links to the minimal spanning tree. These

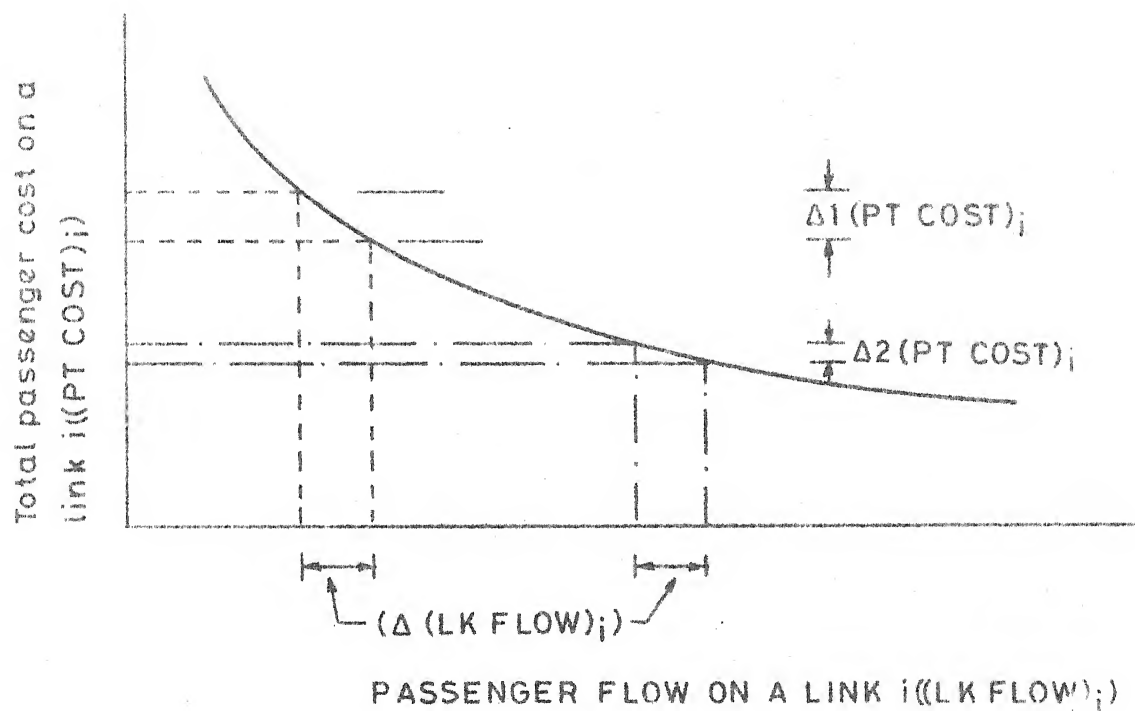


FIG.22 RELATIONSHIP BETWEEN TOTAL PASSENGER COST AND PASSENGER FLOW FOR BUS TRANSIT SYSTEM.

two ways of looking at the problem results into the two different approaches to solve it, backward or forward. Scott (1969) has tested both the approaches, and concludes that 'on all counts the backward algorithm would appear to give better results than the forward algorithm'. So this study also chooses a backward approach, thus starting from the fine-meshed network and proceed towards a coarse-meshed network.

For minimizing the nonlinear function, the objective function and the feasible region must both be convex in order to be sure that a local minimum is also a global minimum. But for the problem under consideration, the objective function and the feasible region are not both convex. So based on Kuhn-Tucker theorem, algorithmic procedure based on the local properties of the problem, is derived to produce a local stationary point which may neither globally maximum nor minimum. The steps in the algorithmic procedure are as follows (Hasselstrom, 1979):

- (i) The shortest paths for all the origin-destination pairs are obtained. In the first iteration, only riding time (RT_i) is considered but in subsequent iterations the sum of riding and vehicle time (as revised in the subsequent steps) i.e. T_i^* is used. Using the shortest paths, all the link

flows $((\text{LKFLOW})_i)$ are estimated for the given 0 - D matrix.

- (ii) The time (T_i) to traverse a link i is revised (T_i^*) based on the link flow $((\text{LKFLOW})_i)$ using the following relationship:

$$T_i^* = ((RT_i)) * \left(1 + \frac{(W).(A)}{2(\text{LKFLOW})_i^{1-B}} \right) \quad (2.9)$$

- (iii) The revised time T_i obtained in step (ii) is used to find the shortest paths for all the 0 - D pairs and revised value of the link flow $((\text{LKFLOW})_i^*)$ is obtained.
- (iv) Compute the total link time i.e. $LT_i = (T_i)^* ((\text{LKFLOW})_i^*)$ and total time for the network i.e.

$$TLT = \sum_i (T_i)^* ((\text{LKFLOW})_i^*) .$$

- (v) If any of the link time (i.e. LT_i) or total link time (TLT) gets changed in step (iv) then the procedure is repeated starting with step (ii) otherwise it is stopped. Fig. 2.3 shows the above procedure.

2.7 Procedure for Generation of Routes

A large set of all possible routes be generated and then optimal ones alongwith their frequencies be

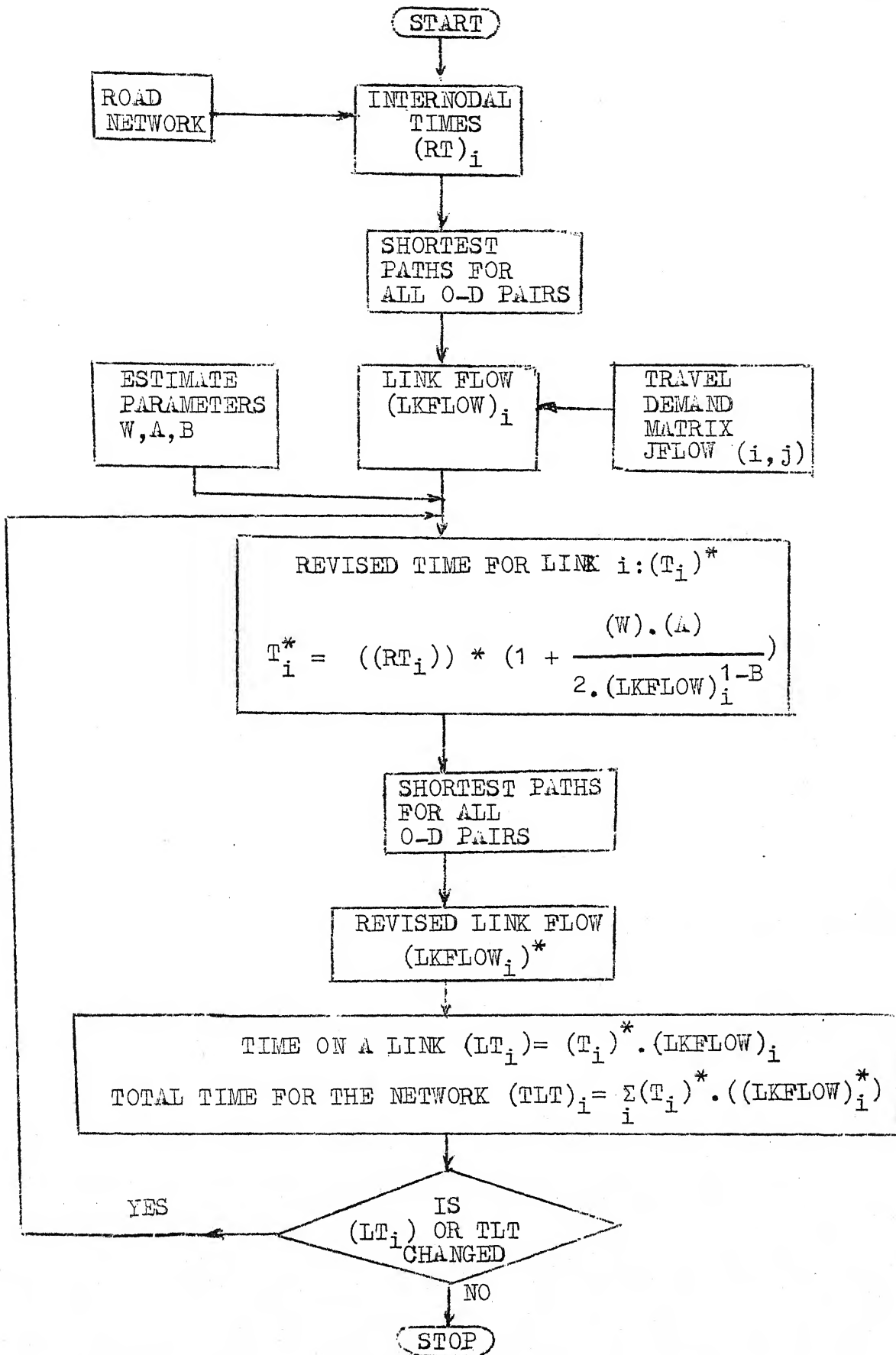


FIG. 2.3 : PROCEDURE FOR CONCENTRATING PASSENGER FLOW

selected using Linear Programming, so that the number of transfers saved is maximized. For a large network it is not necessary to generate a route between every O - D pair, otherwise some nonfeasible routes will be generated. So, a heuristic procedure is developed to generate sufficiently large number of routes which satisfy the following requirements:

- (i) The length of the route should not be less than the minimum length specified for the particular problem under study.
- (ii) The path of the route between two terminating stations should not meander excessively from the shortest path.
- (iii) There should not be any backtracking on the route.

To decide the terminating stations it is desirable that the major generation should have the routes through them. The routes be also generated from other stations so as to satisfy the entire O - D matrix. As discussed in Chapter 1 (Section 1.3) the various models of bus transit planning indicate that firstly the routes between the major generators are fixed but the difficulty is that of satisfying the various requirements of a route in an optimal way. In this method the paths of routes between closer terminals are first decided and then expanded for the distant terminals.

Already developed paths are of great significance in location of the paths of the routes between the distant terminals. In a nutshell, the procedure is as follows:

- (i) Routes are first generated for the O - D pair which have direct links.
- (ii) The O - D pairs which are not directly connected are divided into various groups according to shortest distance between them. The generation of routes is done by first analyzing closer O - D pairs and then expanding for distant O - D pairs.
- (iii) The node (K) is inserted between the O - D pair (i-j) such that the distance of the selected path i-k-j does not exceed twice the shortest distance between i and j.
- (iv) All the routes generated are used to find if any traffic demand for a O - D pair is left out. If it is so, new routes are generated between these O - D pairs. Fig. 2.4 shows the above procedure.

2.8 Transfers Saved on a Route

When the route terminates at the node, the passengers destined for some other node have to transfer at this node. If the route (Fig. 2.5) on link l goes to the next link k, then the flow of those passengers who travelled on both the

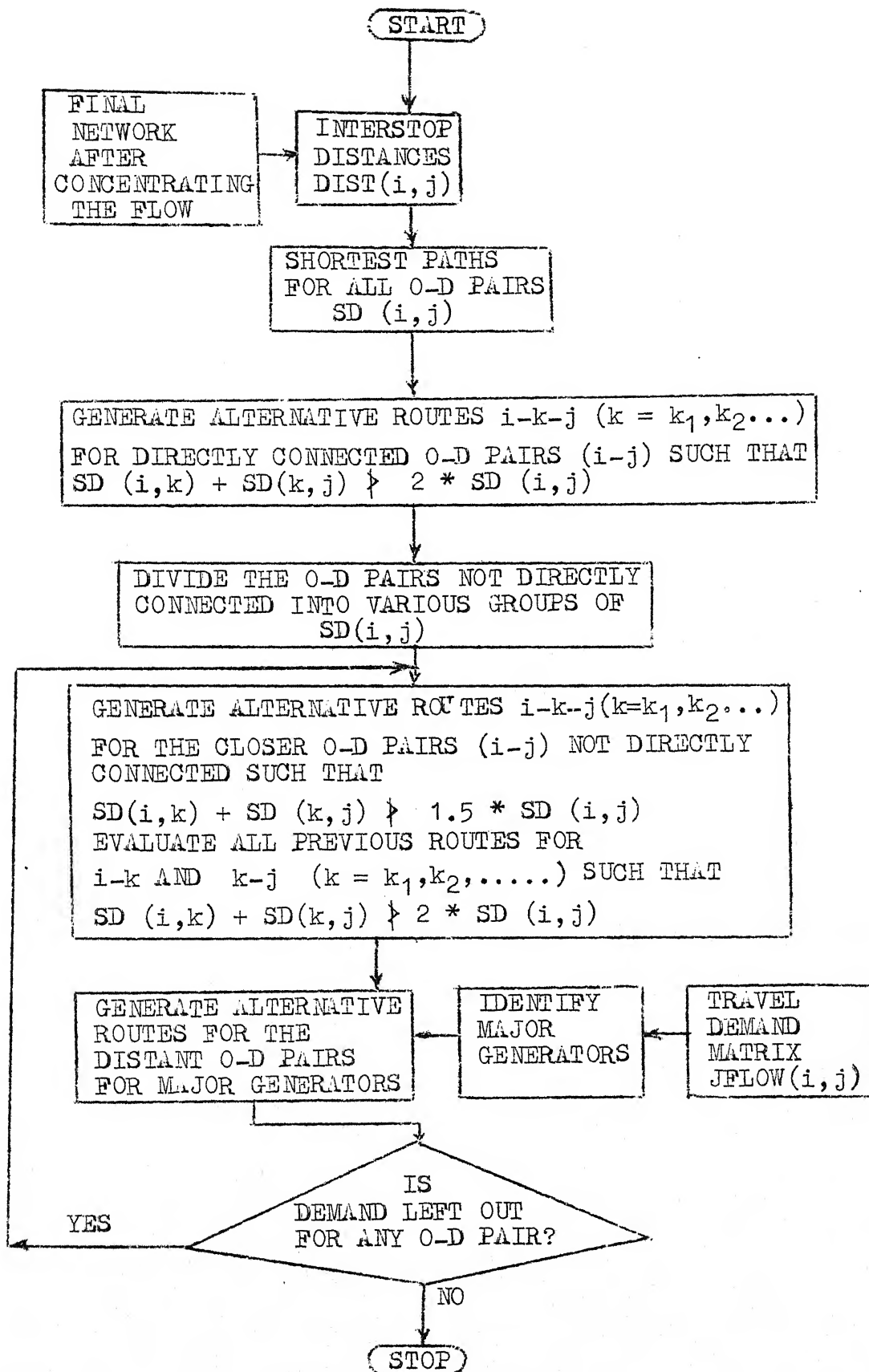


FIG. 2.4 : PROCEDURE FOR GENERATING POSSIBLE ROUTES

links 1 and k save the transfer at the intermediate node. When number of routes pass a node, there are a large number of turning flows at the nodes. It is proposed in this model to maximize the number of transfers saved. The various turning movements on a small network are shown in Fig. 2.5(b). Let $(\text{TURNFL})_{1k}$ be the number of passengers per day going directly from link 1 to link k or vice versa. The estimated number of bus trips per day is $(\text{NOBUS})_1$ on link 1. If a route goes directly from link 1 to link k, the number of transfers saved per route trip for the route and this turning flow, is estimated by following relationship:

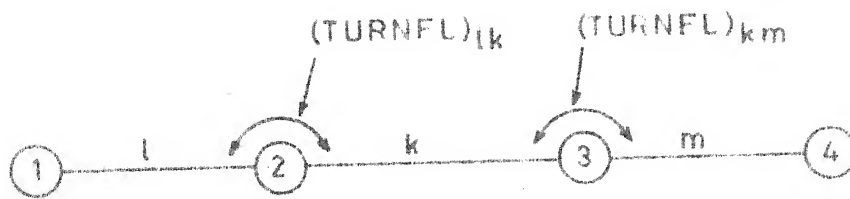
$$(\text{NOTRAN})_{pr} = \frac{(\text{TURNFL})_{1k}}{\text{Minimum } \{(\text{NOBUS})_1, (\text{NOBUS})_k\}} \quad (2.10)$$

where

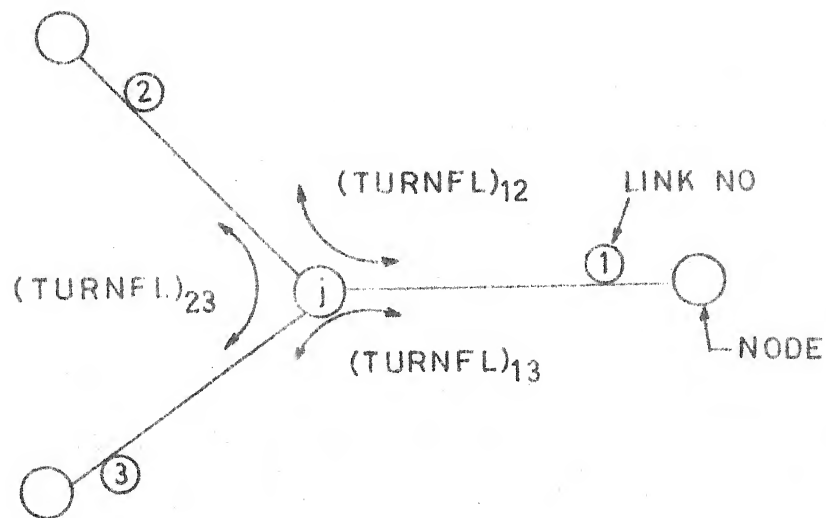
$(\text{NOTRAN})_{pr}$ = Number of transfers saved for p^{th} turning flow of route r.

$\text{Minimum } \{(\text{NOBUS})_1, (\text{NOBUS})_k\}$ = The minimum value of the number of bus trips on the two links 1 and k.

The logic behind this relationship (Eqn. 2.10) is that no more than $\text{minimum } \{(\text{NOBUS})_1, (\text{NOBUS})_k\}$ buses can go directly from link 1 to link k, and that the turning



(a) TURNING MOVEMENTS ALONG A ROUTE



(b) TURNING MOVEMENTS AT A NODE j IN A PART OF A NETWORK

FIG. 25 NUMBER OF TRANSFERS SAVED ON A ROUTE.

passengers are evenly distributed on these links. This is normally a pessimistic estimate as other routes pass link l and k (but not both) as well and these should be subtracted.

The various steps for calculating the number of transfers saved on a sample route (Fig.2.5(a)) are as follows:

- (i) Calculate the turning flow at a node i $(TURNFL)_{lk}$ where links l and k intersect by the following relationship:

$$(TURNFL)_{lk} = \sum_{t=i+1}^{NONODS} \sum_{s=1}^{i-1} JFLOW(s,t) \quad (2.11)$$

where

$JFLOW(s,t)$ = Flow of passengers between the O-D pair s-t.

$NONODS$ = Number of nodes in a route.

- (ii) Estimate the number of bus trips in each direction on the links of a route using the following relationship (Eqn. 2.5).

$$(NOBUS)_l = A ((LKFLOW)_l)^B$$

The link flow on link l i.e. $(LKFLOW)_l$ connecting the nodes i and j, is found out by the following relationship:

$$(LKFLOW)_l = \sum_{t=i+1}^{NONODS} \sum_{s=1}^i JFLOW(s,t) \quad (2.12)$$

The value of $JFLOW(s,t)$ is obtained from the O-D matrix.

- (iii) The number of transfers saved at each node of a route is estimated by Eqn. 2.10.
- (iv) The number of transfers saved is calculated for each turning flow along the route and added to the total for the route, to obtain the total number of transfers saved by a route, i.e. $(TTRAN)_r$. Fig. 2.6 shows the above procedure.

2.9 Model for Simultaneous Choice of Routes and Frequencies

The routing model estimates where the passengers are expected to travel in the optimal route system considering passenger riding time cost and operation cost. A large set of all possible routes which satisfy certain practical constraints is also generated. In this phase, optimal set of routes and their frequencies are obtained such that as many transfers as possible are avoided. The problem is formulated and solved as a linear programming problem(LP).

The objective function is

$$\text{Maximize } Z = \sum_{p=1}^{TTF} (NOTRN)_p \quad (2.13)$$

where

TTF = Total number of turning flows in a networks.

$(NOTRN)_p$ = Number of transfers saved for the p^{th} turning flow.

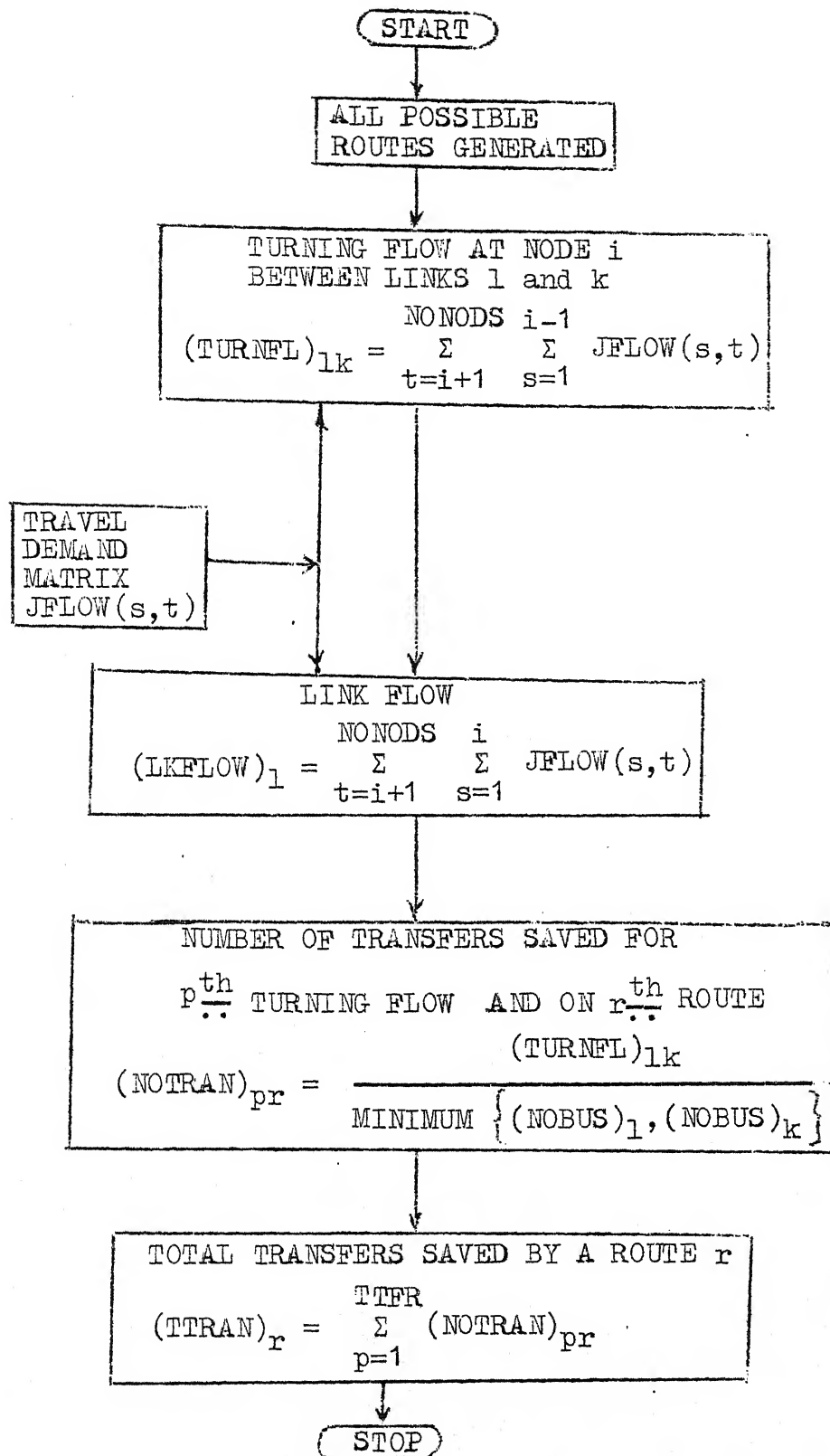


FIG. 2.6 : PROCEDURE FOR CALCULATING NUMBER OF TRANSFERS
SAVED BY A ROUTE

$$(\text{NOTRN})_p = \sum_{r=1}^{NR} (\text{NOTRAN})_{pr} (\text{FREQ})_r \quad \forall p \quad (2.14)$$

where

$(\text{NOTRAN})_{pr}$ = Number of transfers saved for p^{th} turning flow of route r

NR = Number of routes in a network

$(\text{FREQ})_r$ = Frequency on route r .

Substituting the value of $(\text{NOTRN})_p$ the objective function (Eqn. 2.13) becomes:

$$Z = \sum_{r=1}^{NR} \sum_{p=1}^{TFR} (\text{NOTRAN})_{pr} (\text{FREQ})_r \quad (2.15)$$

$$Z = \sum_{r=1}^{NR} (\text{TTRAN})_r (\text{FREQ})_r \quad (2.16)$$

where

$$(\text{TTRAN})_r = \sum_{p=1}^{TFR} (\text{NOTRAN})_{pr} \quad \forall r \quad (2.17)$$

TFR = Number of turning flows in a route.

The problem becomes

$$\text{Maximize } Z = \sum_{r=1}^{NR} (\text{TTRAN})_r (\text{FREQ})_r \quad (2.18)$$

Subject to following sets of constraints:

$$(i) \quad \sum_{r=1}^{NR} (\text{NOTRAN})_{pr} \cdot (\text{FREQ})_r \leq (\text{MAXTFL})_p \quad \forall p \quad (2.19)$$

$$(ii) \quad \sum_{r=1}^{NR} (\text{RTIME})_r \cdot (\text{FREQ})_r \leq (\text{OT}) \cdot (\text{OPF}) \quad (2.20)$$

$$(iii) \quad 0 \leq (FREQ)_r \leq (MAXFRE)_r \quad r \quad (2.21)$$

$$(iv) \quad (NOTRN)_p \geq 0 \quad (2.22)$$

where OT = Operating time (hrs)

$(TTRAN)_r$ = Total number of transfers saved by a route r .

$(MAXTFL)_p$ = Maximum value of the turning flow for the p^{th} turning movement.

$(RTIME)_r$ = Round trip time on route r .

$(MAXFRE)_r$ = Maximum frequency of route r .

OFF = Operating fleet size.

The constraint set (i) (Eqn. 2.19) contains TTF equations where TTF is the total number of turning flows in the network. The different values of the p^{th} turning movement are obtained for various routes. From these, the maximum value of the p^{th} turning movement is found out. So if turning flow p is of the size $(MAXTFL)_p$, no more than this number of transfers can be saved for this turning flow.

The constraint set (ii) (Eqn. 2.20) takes into consideration the operating fleet size. The operating fleet size is the actual number of buses operating on the road. The round trip time, i.e. $(RTIME)_r$ for a route is

found out by calculating the time to travel the total route length $(TRL)_r$ and adding the lay over time $(LOT)_r$. The round trip time on a route r is calculated by the following formula:

$$(RTIME)_r = \frac{(TRL)_r}{AVERS P} + (LOT)_r \quad (2.23)$$

where

$AVERS P$ = Average speed of the bus (Kmph).

The average speed of the bus is estimated using the values of different speeds in different areas of the city. The lay over time at the destination of a route is estimated taking into consideration the route length. The sum of the product of the frequency and round trip time of all routes should not exceed the product of operating fleet size and operating time.

The constraint set (iii) (Eqn. 2.21) takes into consideration the upper bound on frequency for every route. The value of frequency which comes into the optimal solution should lie between one and maximum frequency.

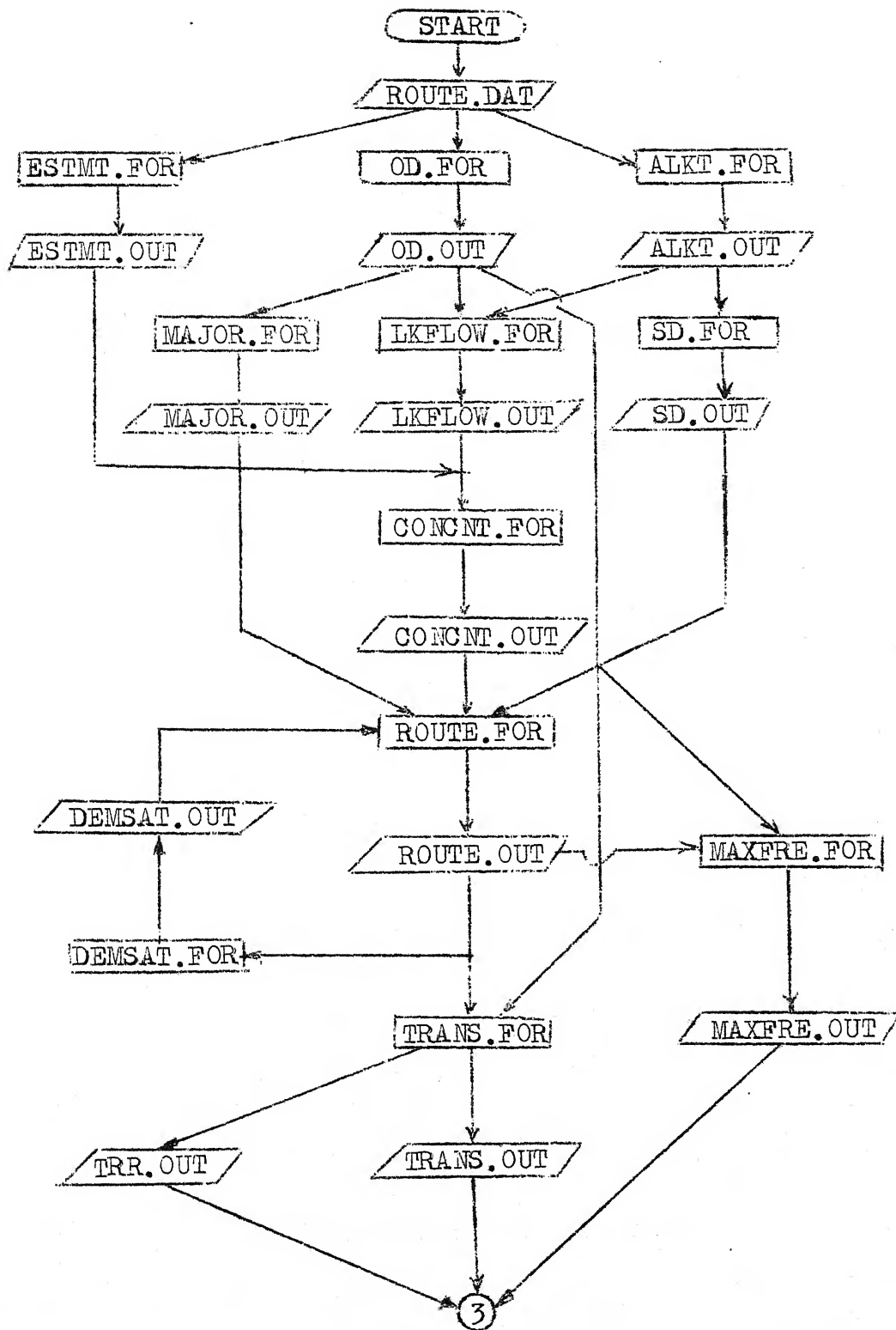
The constraint set (iv) (Eqn. 2.22) takes into consideration the non-negativity requirements of the number of transfers saved for $p_{..}^{th}$ turning flow.

The model simultaneously gives the optimal set of routes and their frequencies for a given fleet size, so as to maximize the number of transfers saved. Experiment can be performed with different fleet sizes.

2.10 Development of Computer Programmes

The model for the simultaneous choice of routes and their frequencies and the various associated submodels has been discussed in the previous sections. The model is quite complex as it involves a lot of evaluation and data processing. A complete system of the computer programmes have been developed for the model. The system of programmes alongwith their interactions and working is shown in Fig. 2.7. The details of the system are as given below:

- (i) To get the desire O - D matrix (OD.OUT), the computer programme OD.FOR is developed (Fig.2.1). Input to this programme is ROUTE.DAT, which contains the data for all routes like number of stops on each route, number of passengers on each route and code number for the stops on the route.
- (ii) To get the link table (ALKT.OUT) for the network, the programme ALKT.FOR is developed. Input to this programme is file ROUTE.DAT. Output from this programme is ALKT.OUT.



Contd....

- (iii) To get the values of the coefficients W, A and B, for the concentration of flow a programme ESTMT.FOR is developed. As a result we get the relationship between the flow of passengers and the number of bus trips in unit time. Input to this programme ESTMT. FOR is ROUTE.DAT. Output file is ESTMT.OUT.
- (iv) A programme LKFLOW.FOR is developed to get the link flow on each link using shortest path algorithm. Input to this programme is two files OD.OUT and ALKT.OUT . Output from this programme is LKFLOW.OUT.
- (v) A programme SD.FOR is developed to get the shortest distance matrix for all O-D pairs using shortest path algorithm. Input to this programme is ALKT.OUT. Output from this programme is SD.OUT.
- (vi) A programme MAJOR.FOR is developed to scan the major O-D pairs from the file OD.OUT. Output from this programme is MAJOR.OUT which is used for the route generation.
- (vii) A programme CONCNT.FOR is developed to evaluate the various networks of links and to get the final network with minimum total cost. Input files are LKFLOW.OUT and ESTMT.OUT. Output file is CONCNT.OUT.

- (viii) A programme ROUTE.FOR is developed to generate the routes sequentially i.e. starting with those O-D pairs which are directly connected. Then the O-D pairs which are not directly connected are classified into various groups according to the shortest distance between them. Routes are first generated for the closer O-D pairs. By taking the output of closer O-D pairs as the input, routes for distant O-D pairs are generated. The input files are CONCNT.OUT, MAJOR.OUT and SD.OUT. Output from this file programme is ROUTE.OUT.
- (ix) A programme DEMSAT.FOR is developed to check whether almost all demand is satisfied or not. Input file is ROUTE.OUT. Output file from this programme is DEMSAT.OUT. If the demand is not satisfied, some more routes are generated for that unsatisfied demand and this process is continued until almost all demand is satisfied.
- (x) A programme TRANS.FOR is developed to calculate the number of transfers saved by each route. Input files for this programme are OD.OUT and ROUTE.OUT. Output files from this programme are TRR.OUT and TRANS.OUT. The file TRR.OUT gives the value of total transfers saved by each route. The file TRANS.OUT give all details of turning flow and

the number of transfers saved for each turning flow along each route.

- (xi) A programme MAXFRE.FOR is developed to get the maximum value of frequency for every route. Input files are ROUTE.OUT and OD.OUT. Output from this programme is MAXFRE.OUT which gives the maximum frequency on each route.
- (xii) For the LP solution, various programmes are developed to get the fixed parameters of the model namely constraint matrix, resources and objective coefficients. If the number of constraint equations is too large to accomodate in computer memory, the problem can be solved in parts. The various programmes are as follows:
 - (a) A programme RP.FOR is developed to scan those routes and turning flows from the file TRANS.OUT, which are of interest to the part of the network in question. The output files are RP.OUT and RP.OT1. The file RP.OUT contains details of designation of the $p_{\cdot\cdot}^{\text{th}}$ turning flow, its value and number of transfers saved for this turning flow. The file RP.OT1 is used as the counter for the total number of all turning flows of all routes.

- (b) A programme P.FOR is developed to rearrange the file RP.OUT i.e. rearranging all the turning movements on all the routes, so that the number of routes contributing for p_{\dots}^{th} turning movement can be identified. Input to this programme is RP.OUT and RP.OT1. The output files are P.OUT, P1.OUT and P.OT1. The file P.OUT is the arranged file which accumulates the p_{\dots}^{th} turning flow of different routes. This file gives the total number of turning flows. The file P1.OUT gives the value of the number of routes contributing to each p_{\dots}^{th} turning flow. The file P.OT1 is used as a counter for the total number of all turning flows on all routes.
- (c) A programme P2.FOR is developed to get the maximum value of the p_{\dots}^{th} turning flow out of all the turning flows contributed by various routes. Input files are P.OUT, P1.OUT and P.OT1. The output file is P2.OUT.
- (d) A programme SER1.FOR is developed to read the coefficient matrix (i.e. $(\text{NOTRAN})_{pr}$ values). Input files are P.OUT, P.OT1. The output files are SER.OUT and SER1.OUT. The output file SER.OUT gives the values of p, r and $(\text{NOTRAN})_{pr}$. The output file SER1.OUT gives the final value of number of routes in question.

- (e) A programme SER.FOR is developed to get the maximum frequency and route-length for each route for the set of routes in question. Input files for this programme are MAXFRE.OUT, ROUTE.OUT, P.OT1, P.OUT, SER1.OUT. The output file is SER.OT1 which gives the route-length and maximum frequency for each route in question.
- (f) A programme OPF.FOR is developed to get the value of operating fleet for the part of the network in question. The input files are SER1.OUT and SER.OT1. The output file is OPF.OUT which gives the value of operating fleet. The total operating fleet is divided for different parts of network according to the round trip-route time and the maximum frequency of the routes which contribute to the part of the network.
- (g) A programme SETR. FOR is developed to get the value of the total number of transfers saved by each route in question. The input files are SER.OUT, TRR.OUT and SER1.OUT. The output file is SETR.OUT.
- (h) A programme AA.FOR is developed to get the value of coefficients for constraint on the upper value of the frequency. Input files are SER1.OUT and P.OT1. The output file is AA.DAT.

After getting all the values of fixed parameters from the files SETR.OUT, SER1.OUT, OPF.OUT, SER.OT1, P2.OUT, AA.DAT and P.OT1, a programme LP.FOR is developed using IMSL subroutine Zx3LP and the solution containing the optimal number of routes and their frequencies is obtained.

3 APPLICATION OF THE MODEL

3.1 General

The model for generating an urban bus transit network with simultaneous choice of routes and frequencies through heuristic methods is described in the previous chapter. For the model to be of real use, it should be tested and validated using real world data. This model is applied in this study to the city of Ahmedabad for the design of the bus transit system. The following sections describe the application and the analysis of results.

3.2 Ahmedabad and its Bus Transit System

Ahmedabad is the sixth largest metropolis in India and in the western part of the country it ranks second in population next only to Bombay. Ahmedabad is the largest industrial city in the state of Gujarat with a population of 2.1 million which is likely to touch 3.6 million in 1991. It is the second fastest growing city ranking next only to Delhi. The municipal area is 24269 acres and the walled city area is 1361 acres. The population density of the city has risen from 11276 persons per square km (1941) to 17053 persons per square km in 1971 (WB, 1976).

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The city of Ahmedabad is accessible by means of seven major highways and five major rail links of broad gauge and metre gauge from different parts of the state and the country. On account of high accessibility offered by the regional transport system i.e. road and rail, the city has physically grown in concentric shape. The city can be divided on area-wise basis into five zones namely Central, North, South, East and West. The Central zone i.e. walled city accounts for nearly 30 percent of the total population and has the highest density in the city. The North Zone has got textile industries. The South Zone has got industries related to iron and other small scale industries. The East Zone is commercial and residential. The West Zone has got educational and research institutions and is on the left bank of the river Subarmati. The most conspicuous feature of the land use system is the total inadequacy of the area devoted to roads and streets in Ahmedabad. In comparison with the cities of western world (London 23, Paris 25, Washington 30 percents) the 12.9 percent of the total area devoted to roads and streets in Ahmedabad is extremely low. The existing land use pattern for the city is shown in Fig. 3.1.

Bus transportation system in the city is operated by 'The Ahmedabad Municipal Transport Service' (A.M.T.S.),

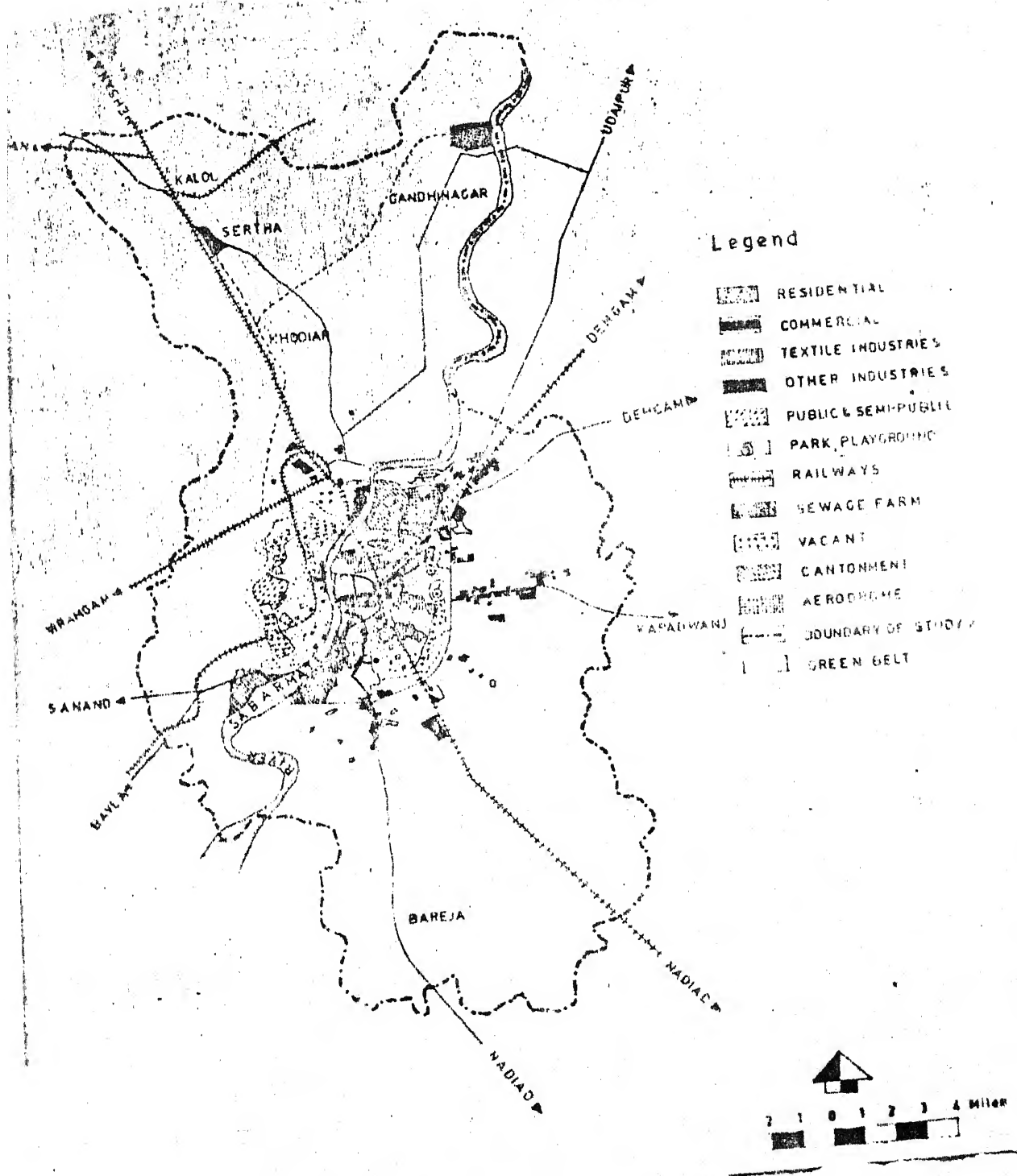


FIG.31: EXISTING LAND USE FOR THE CITY OF AHMEDABAD.

which maintains a total operating fleet of 670 buses to cater to the needs of metropolis and the satellite townships. The A.M.T.S. has tried to keep pace with the rapid growth of Ahmedabad city and operates 191 bus routes, offering 10,600 scheduled trips, catering for approximate 8.5 lakh passengers per day (8.00 A.M. to 1.30 A.M.). There are 71 long distance services with route length of more than 12 kilometres. The average route length is 8.0 kilometres. The transit network consists of 745 stops covered by the A.M.T.S. The minor stops are not considered and their demands are transferred to the adjoining major nodes (with high passenger volume). The final network consists of 134 nodes (Fig. 3.2). The index for the various nodes shown in the Fig. 3.2 is given in Appendix I alongwith the number of existing routes touching these nodes.

The A.M.T.S. have been put to severe limitations on account of:

- (i) Route expansion has largely been carried out on socio-political demands in the absence of a well-defined route location policy. Increase in the routes inconsistent with the fleet size have resulted in parallel operations, low load factors and low frequencies. As a result of this nearly one-third of the existing routes are uneconomical.

- (ii) The present routing system lays heavy emphasis on the utilisation of Lal-Darwaja (Node 1) and Kalupur (Node 4) terminals. Nearly 174 of the existing 191 routes converge at either of these terminals. The facilities of these are already saturated and suffer from poor accessibility conditions.
- (iii) The total annual passenger traffic has more or less remained static at 5.6 lakhs passengers per day between 1971 and 1976. Inconsistencies in passenger traffic trends coupled with increased usage of auto-rickshaws largely explain the deficiency in supply characteristics of public transport system.
- (iv) The existing vehicle utilisation of 180 km/day is low in comparison to the prevailing norms for other cities (Table 3.1).

There is an urgent need for the rationalization of the existing transit route network for providing an efficient city bus service.

3.3 Data Requirements for the Model

Descriptive and quantitative information (data) about the particular system to be investigated by modelling is a prerequisite for the problem definition and problem formulation. The routes are to be constructed through

TABLE 3.1 : OPERATING CHARACTERISTICS OF BUSES IN
AHMEDABAD AND OTHER CITIES (1978/1979)

Sl. No.	Characteristics	Bombay	Delhi	Ahmedabad	Vadodra	Lahore
1	Population (millions)	7.0	5.0	2.0	0.6	3.0
2	Buses for 100,000 population	24	46	24	23	12
3	Daily passengers carried per bus	2330	1150	1416	1170	612
4	Approximate average passenger trip-length (km)	5.5	9.9	4.14	3.0	7.5
5	Daily operated distance per bus (km)	219	220	180	138	141

the demand points in the city network. Therefore, data requirements for the routing model are:

- (i) the demand points or nodes and prospective nodes in the urban street network;
- (ii) the internodal distances and the corresponding riding times;
- (iii) Origin-Destination Matrix;
- (iv) operating Fleet-size.

3.4 Analysis of Field Data

3.4.1 Introduction

The accuracy of the system model depends upon the extent of availability of reliable data. Some data in raw form were available from the A.M.T.S. offices. To start with, the existing routes operated by A.M.T.S. are taken. The nodes touched by various routes and the route lengths are given in Table 3.2. The characteristics of all the 191 routes in terms of frequency (Number of trips in a day), trip travel time, number of buses operating, daily average traffic income, average load factor and the maximum fare for each of the route are given in Table 3.3. Table 3.2 indicates that the route lengths are between the range of 2.6 kms to 20 kms. The average route length is 8.00 kms. Table 3.3 indicates that the number of scheduled

TABLE 3.2 (CONTD.)

ROUTE		NODES TOUCHED BY THE ROUTE		ROUTE	
NO	LENGTH				
44	15	15	14	15	15
44	16	16	15	14	15
44	17	17	16	15	14
44	18	18	17	16	15
44	19	19	18	17	16
44	20	20	19	18	17
44	21	21	20	19	18
44	22	22	21	20	19
44	23	23	22	21	20
44	24	24	23	22	21
44	25	25	24	23	22
44	26	26	25	24	23
44	27	27	26	25	24
44	28	28	27	26	25
44	29	29	28	27	26
44	30	30	29	28	27
44	31	31	30	29	28
44	32	32	31	30	29
44	33	33	32	31	30
44	34	34	33	32	31
44	35	35	34	33	32
44	36	36	35	34	33
44	37	37	36	35	34
44	38	38	37	36	35
44	39	39	38	37	36
44	40	40	39	38	37
44	41	41	40	39	38
44	42	42	41	40	39
44	43	43	42	41	40
44	44	44	43	42	41
44	45	45	44	43	42
44	46	46	45	44	43
44	47	47	46	45	44
44	48	48	47	46	45
44	49	49	48	47	46
44	50	50	49	48	47
44	51	51	50	49	48
44	52	52	51	50	49
44	53	53	52	51	50
44	54	54	53	52	51
44	55	55	54	53	52
44	56	56	55	54	53
44	57	57	56	55	54
44	58	58	57	56	55
44	59	59	58	57	56
44	60	60	59	58	57
44	61	61	60	59	58
44	62	62	61	60	59
44	63	63	62	61	60
44	64	64	63	62	61
44	65	65	64	63	62
44	66	66	65	64	63
44	67	67	66	65	64
44	68	68	67	66	65
44	69	69	68	67	66
44	70	70	69	68	67
44	71	71	70	69	68
44	72	72	71	70	69
44	73	73	72	71	70
44	74	74	73	72	71
44	75	75	74	73	72
44	76	76	75	74	73
44	77	77	76	75	74
44	78	78	77	76	75
44	79	79	78	77	76
44	80	80	79	78	77
44	81	81	80	79	78
44	82	82	81	80	79
44	83	83	82	81	80
44	84	84	83	82	81
44	85	85	84	83	82
44	86	86	85	84	83
44	87	87	86	85	84
44	88	88	87	86	85
44	89	89	88	87	86
44	90	90	89	88	87
44	91	91	90	89	88
44	92	92	91	90	89
44	93	93	92	91	90
44	94	94	93	92	91
44	95	95	94	93	92
44	96	96	95	94	93
44	97	97	96	95	94
44	98	98	97	96	95
44	99	99	98	97	96
44	100	100	99	98	97
44	101	101	100	99	98
44	102	102	101	100	99
44	103	103	102	101	100
44	104	104	103	102	101
44	105	105	104	103	102
44	106	106	105	104	103
44	107	107	106	105	104
44	108	108	107	106	105
44	109	109	108	107	106
44	110	110	109	108	107
44	111	111	110	109	108
44	112	112	111	110	109
44	113	113	112	111	110
44	114	114	113	112	111
44	115	115	114	113	112
44	116	116	115	114	113
44	117	117	116	115	114
44	118	118	117	116	115
44	119	119	118	117	116
44	120	120	119	118	117
44	121	121	120	119	118
44	122	122	121	120	119
44	123	123	122	121	120
44	124	124	123	122	121
44	125	125	124	123	122
44	126	126	125	124	123
44	127	127	126	125	124
44	128	128	127	126	125
44	129	129	128	127	126
44	130	130	129	128	127
44	131	131	130	129	128
44	132	132	131	130	129
44	133	133	132	131	130
44	134	134	133	132	131
44	135	135	134	133	132
44	136	136	135	134	133
44	137	137	136	135	134
44	138	138	137	136	135
44	139	139	138	137	136
44	140	140	139	138	137
44	141	141	140	139	138
44	142	142	141	140	139
44	143	143	142	141	140
44	144	144	143	142	141
44	145	145	144	143	142
44	146	146	145	144	143
44	147	147	146	145	144
44	148	148	147	146	145
44	149	149	148	147	146
44	150	150	149	148	147
44	151	151	150	149	148
44	152	152	151	150	149
44	153	153	152	151	150
44	154	154	153	152	151
44	155	155	154	153	152
44	156	156	155	154	153
44	157	157	156	155	154
44	158	158	157	156	155
44	159	159	158	157	156
44	160	160	159	158	157
44	161	161	160	159	158
44	162	162	161	160	159
44	163	163	162	161	160
44	164	164	163	162	161
44	165	165	164	163	162
44	166	166	165	164	163
44	167	167	166	165	164
44	168	168	167	166	165
44	169	169	168	167	166
44	170	170	169	168	167
44	171	171	170	169	168
44	172	172	171	170	169
44	173	173	172	171	170
44	174	174	173	172	171
44	175	175	174	173	172
44	176	176	175	174	173
44	177	177	176	175	174
44	178	178	177	176	175
44	179	179	178	177	176
44	180	180	179	178	177
44	181	181	180	179	178
44	182	182	181	180	179
44	183	183	182	181	180
44	184	184	183	182	181
44	185	185	184	183	182
44	186	186	185	184	183
44	187	187	186	185	184
44	188	188	187	186	185
44	189	189	188	187	186
44	190	190	189	188	187
44	191	191	190	189	188
44	192	192	191	190	189
44	193	193	192	191	190
44	194	194	193	192	191
44	195	195	194	193	192
44	196	196	195	194	193
44	197	197	196	195	194
44	198	198	197	196	195
44	199	199	198	197	196
44	200	200	199	198	197

CONTD.....

TABLE 3.2 (CONTD.)

ROUTE		NODES		TOUCHED		BY THE		ROUTE	
NO	LENGTH	NO	LENGTH	NO	LENGTH	NO	LENGTH	NO	LENGTH
1	10	1	10	1	10	1	10	1	10
2	10	1	10	1	10	1	10	1	10
3	10	1	10	1	10	1	10	1	10
4	10	1	10	1	10	1	10	1	10
5	10	1	10	1	10	1	10	1	10
6	10	1	10	1	10	1	10	1	10
7	10	1	10	1	10	1	10	1	10
8	10	1	10	1	10	1	10	1	10
9	10	1	10	1	10	1	10	1	10
10	10	1	10	1	10	1	10	1	10
11	10	1	10	1	10	1	10	1	10
12	10	1	10	1	10	1	10	1	10
13	10	1	10	1	10	1	10	1	10
14	10	1	10	1	10	1	10	1	10
15	10	1	10	1	10	1	10	1	10
16	10	1	10	1	10	1	10	1	10
17	10	1	10	1	10	1	10	1	10
18	10	1	10	1	10	1	10	1	10
19	10	1	10	1	10	1	10	1	10
20	10	1	10	1	10	1	10	1	10
21	10	1	10	1	10	1	10	1	10
22	10	1	10	1	10	1	10	1	10
23	10	1	10	1	10	1	10	1	10
24	10	1	10	1	10	1	10	1	10
25	10	1	10	1	10	1	10	1	10
26	10	1	10	1	10	1	10	1	10
27	10	1	10	1	10	1	10	1	10
28	10	1	10	1	10	1	10	1	10
29	10	1	10	1	10	1	10	1	10
30	10	1	10	1	10	1	10	1	10
31	10	1	10	1	10	1	10	1	10
32	10	1	10	1	10	1	10	1	10
33	10	1	10	1	10	1	10	1	10
34	10	1	10	1	10	1	10	1	10
35	10	1	10	1	10	1	10	1	10
36	10	1	10	1	10	1	10	1	10
37	10	1	10	1	10	1	10	1	10
38	10	1	10	1	10	1	10	1	10
39	10	1	10	1	10	1	10	1	10
40	10	1	10	1	10	1	10	1	10
41	10	1	10	1	10	1	10	1	10
42	10	1	10	1	10	1	10	1	10
43	10	1	10	1	10	1	10	1	10
44	10	1	10	1	10	1	10	1	10
45	10	1	10	1	10	1	10	1	10
46	10	1	10	1	10	1	10	1	10
47	10	1	10	1	10	1	10	1	10
48	10	1	10	1	10	1	10	1	10
49	10	1	10	1	10	1	10	1	10
50	10	1	10	1	10	1	10	1	10
51	10	1	10	1	10	1	10	1	10
52	10	1	10	1	10	1	10	1	10
53	10	1	10	1	10	1	10	1	10
54	10	1	10	1	10	1	10	1	10
55	10	1	10	1	10	1	10	1	10
56	10	1	10	1	10	1	10	1	10
57	10	1	10	1	10	1	10	1	10
58	10	1	10	1	10	1	10	1	10
59	10	1	10	1	10	1	10	1	10
60	10	1	10	1	10	1	10	1	10
61	10	1	10	1	10	1	10	1	10
62	10	1	10	1	10	1	10	1	10
63	10	1	10	1	10	1	10	1	10
64	10	1	10	1	10	1	10	1	10
65	10	1	10	1	10	1	10	1	10
66	10	1	10	1	10	1	10	1	10
67	10	1	10	1	10	1	10	1	10
68	10	1	10	1	10	1	10	1	10
69	10	1	10	1	10	1	10	1	10
70	10	1	10	1	10	1	10	1	10
71	10	1	10	1	10	1	10	1	10
72	10	1	10	1	10	1	10	1	10
73	10	1	10	1	10	1	10	1	10
74	10	1	10	1	10	1	10	1	10
75	10	1	10	1	10	1	10	1	10
76	10	1	10	1	10	1	10	1	10
77	10	1	10	1	10	1	10	1	10
78	10	1	10	1	10	1	10	1	10
79	10	1	10	1	10	1	10	1	10
80	10	1	10	1	10	1	10	1	10
81	10	1	10	1	10	1	10	1	10
82	10	1	10	1	10	1	10	1	10
83	10	1	10	1	10	1	10	1	10
84	10	1	10	1	10	1	10	1	10
85	10	1	10	1	10	1	10	1	10
86	10	1	10	1	10	1	10	1	10
87	10	1	10	1	10	1	10	1	10
88	10	1	10	1	10	1	10	1	10
89	10	1	10	1	10	1	10	1	10
90	10	1	10	1	10	1	10	1	10
91	10	1	10	1	10	1	10	1	10
92	10	1	10	1	10	1	10	1	10
93	10	1	10	1	10	1	10	1	10
94	10	1	10	1	10	1	10	1	10
95	10	1	10	1	10	1	10	1	10
96	10	1	10	1	10	1	10	1	10
97	10	1	10	1	10	1	10	1	10
98	10	1	10	1	10	1	10	1	10
99	10	1	10	1	10	1	10	1	10
100	10	1	10	1	10	1	10	1	10

CONTD.....

TABLE 3.2 (CONTD.)

ROUTE NO	ROUTE LENGTH	NODES TOUCHED	BY THE ROUTE
1	5	57 103 51 135	
2	5	130	
3	5	130	
4	5	50 136	
5	5	50 136	
6	5	50 136	
7	5	50 136	
8	5	50 136	
9	5	50 136	
10	5	50 136	
11	5	50 136	
12	5	50 136	
13	5	50 136	
14	5	50 136	
15	5	50 136	
16	5	50 136	
17	5	50 136	
18	5	50 136	
19	5	50 136	
20	5	50 136	
21	5	50 136	
22	5	50 136	
23	5	50 136	
24	5	50 136	
25	5	50 136	
26	5	50 136	
27	5	50 136	
28	5	50 136	
29	5	50 136	
30	5	50 136	
31	5	50 136	
32	5	50 136	
33	5	50 136	
34	5	50 136	
35	5	50 136	
36	5	50 136	
37	5	50 136	
38	5	50 136	
39	5	50 136	
40	5	50 136	
41	5	50 136	
42	5	50 136	
43	5	50 136	
44	5	50 136	
45	5	50 136	
46	5	50 136	
47	5	50 136	
48	5	50 136	
49	5	50 136	
50	5	50 136	
51	5	50 136	
52	5	50 136	
53	5	50 136	
54	5	50 136	
55	5	50 136	
56	5	50 136	
57	5	50 136	
58	5	50 136	
59	5	50 136	
60	5	50 136	
61	5	50 136	
62	5	50 136	
63	5	50 136	
64	5	50 136	
65	5	50 136	
66	5	50 136	
67	5	50 136	
68	5	50 136	
69	5	50 136	
70	5	50 136	
71	5	50 136	
72	5	50 136	
73	5	50 136	
74	5	50 136	
75	5	50 136	
76	5	50 136	
77	5	50 136	
78	5	50 136	
79	5	50 136	
80	5	50 136	
81	5	50 136	
82	5	50 136	
83	5	50 136	
84	5	50 136	
85	5	50 136	
86	5	50 136	
87	5	50 136	
88	5	50 136	
89	5	50 136	
90	5	50 136	
91	5	50 136	
92	5	50 136	
93	5	50 136	
94	5	50 136	
95	5	50 136	
96	5	50 136	
97	5	50 136	
98	5	50 136	
99	5	50 136	
100	5	50 136	

CONTD.....

TABLE 3.3 : DETAILS OF EXISTING BUS ROUTES TO AHMEDABAD

ROUTE NO.	NO. OF TRIPS	TRIP TIME	NO. OF BUSES	DAILY AVERAGE INCOME	AVERAGE LOAD FACTOR %	MAXIMUM PAPE
1	20	25	1	336	47	25
2	20	20	1	336	47	25
3	26	20	1	250	40	25
4	26	21	1	250	40	25
5	15	24	1	239	34	30
6	15	24	1	239	34	30
7	40	15	4	1439	63	35
8	40	15	4	1439	63	35
9	40	20	4	1382	63	35
10	40	22	4	1282	63	35
11	47	30	3	1234	57	50
12	47	30	2	780	56	50
13	41	30	3	1491	60	50
14	41	32	4	1492	60	45
15	47	26	2	974	54	60
16	15	25	1	175	43	45
17	135	55	7	3641	53	60
18	30	21	1	394	49	45
19	48	30	4	1499	70	45
20	120	50	7	4547	63	55
21	22	25	1	240	36	35
22	78	36	3	1514	53	55
23	37	32	2	673	51	55
24	28	80	2	802	51	70
25	66	45	3	1353	51	60
26	21	35	1	402	46	55
27	41	50	2	920	54	60
28	22	39	1	360	41	60
29	82	45	4	1765	51	60
30	22	45	1	433	44	60
31	30	21	1	486	55	55
32	56	30	2	1016	55	55
33	22	30	1	361	46	55
34	14	9	1	271	38	40
35	20	50	1	226	34	45
36	120	14	1	271	38	45
37	152	50	2	732	46	60
38	199	50	1	476	48	65
39	20	35	1	354	38	55
40	14	35	1	408	45	70
41	72	20	3	726	56	30
42	102	20	3	832	50	30
43	30	25	1	216	39	30
44	35	30	1	244	30	50
45	60	30	3	1158	48	55
46	107	22	4	1240	45	55
47	14	20	1	100	34	55
48	22	20	1	277	38	50
49	28	40	3	1042	45	55
50	15	42	1	69	30	35

,contd.....

TABLE 3.3 (contd.)

DATE	TIME	TRIP TIME	NO. OF BUSES	DAILY AVERAGE INCLIN	AVERAGE LOAD FACTOR %	MAX. FARE
7-1	60	35	2	589	54	45
7-2	66	21	3	342	50	45
7-3	100	35	5	1723	56	50
7-4	60	35	2	411	49	25
7-5	20	30	1	283	49	40
7-6	12	60	1	78	31	50
7-7	101	60	7	3373	65	60
7-8	15	25	1	221	36	30
7-9	75	15	2	140	44	35
7-10	20	40	1	00	35	55
7-11	100	30	10	3522	53	60
7-12	100	35	1	103	32	55
7-13	100	35	6	3242	64	60
7-14	10	20	1	300	59	35
7-15	30	20	3	1220	54	50
7-16	125	20	4	1860	56	45
7-17	12	60	1	254	34	70
7-18	10	25	1	330	50	30
7-19	10	20	1	330	50	30
7-20	10	16	1	270	41	30
7-21	10	20	1	270	41	30
7-22	141	30	9	3468	62	50
7-23	141	20	4	1499	48	45
7-24	63	20	2	877	58	40
7-25	20	15	1	160	24	25
7-26	20	12	1	214	35	25
7-27	20	15	1	214	35	25
7-28	10	48	1	111	42	60
7-29	10	50	1	123	30	60
7-30	93	40	5	1102	46	50
7-31	9	45	1	99	42	60
8-1	24	25	1	245	36	45
8-2	10	50	1	354	52	55
8-3	36	20	1	414	57	30
8-4	110	17	3	1240	58	40
8-5	37	26	1	416	60	40
8-6	53	25	1	142	30	20
8-7	38	14	1	504	77	35
8-8	23	55	1	171	31	70
8-9	115	25	4	1726	54	45
8-10	40	30	2	678	44	50
8-11	20	25	1	78	28	50
8-12	20	35	1	266	36	45
8-13	20	55	1	250	35	50
8-14	36	55	2	961	63	60
8-15	37	55	2	961	61	60
8-16	24	27	4	2225	59	60
8-17	20	32	1	500	51	60
8-18	20	21	1	411	56	60
8-19	21	21	1	264	38	55

contd.....

TABLE 3.3 (contd.)

STATION NO.	DATE	WIND TIME	NO. OF PASSES	DAILY AVERAGE INCOME	AVERAGE LOAD FACTOR %	DAILY FARE
1107	27	25	1	454	42	50
1108	27	25	1	444	42	50
1109	27	25	1	415	53	60
1110	22	22	2	278	48	60
1111	21	25	5	2163	59	60
1112	17	30	1	455	52	60
1113	17	42	2	927	59	55
1114	17	42	3	1383	57	60
1115	17	42	2	891	55	60
1116	17	21	2	1014	62	50
1117	15	17	3	1432	52	50
1118	15	55	1	332	44	60
1119	15	55	1	798	44	60
1120	22	25	1	334	41	55
1121	19	50	1	354	46	55
1122	26	15	1	419	37	50
1123	17	41	1	650	62	60
1124	17	22	2	958	60	55
1125	60	20	3	1918	62	60
1126	24	24	1	355	44	50
1127	34	30	2	666	49	60
1128	187	12	7	4636	66	60
1129	84	12	3	1719	69	60
1130	31	17	3	881	47	70
1131	35	17	3	803	45	65
1132	27	23	2	647	46	55
1133	26	15	6	1983	60	25
1134	107	20	3	804	55	30
1135	47	65	2	484	43	35
1136	71	35	3	1266	55	30
1137	63	26	3	922	54	40
1138	60	25	2	576	48	40
1139	41	40	3	1054	60	60
1140	52	50	3	1119	48	60
1141	47	55	4	1576	50	65
1142	55	35	2	533	39	40
1143	55	24	1	151	29	35
1144	20	45	1	79	39	25
1145	22	28	1	248	37	45
1146	22	65	1	616	39	65
1147	25	36	2	228	35	45
1148	40	16	1	234	37	30
1149	31	39	1	343	50	60
1150	102	50	1	3465	59	60
1151	95	25	3	1377	60	45
1152	117	50	7	3011	63	60
1153	40	16	1	351	51	40
1154	91	60	2	679	45	60
1155	55	32	4	1352	54	55
1156	55	20	1	333	40	30

contd...

TABLE 3.3 (contd.)

ROUTE NO.	NO. OF TRIPS	TRIP TIME	NO. OF BUSES	DAILY AVERAGE INCOME	AVERAGE LOAD FACTOR %	MAXM FARE
151	42	60	3	1222	57	65
152	106	20	4	1309	70	65
153	23	30	1	341	48	50
154	59	30	2	644	45	50
155	30	65	3	985	51	55
156	23	24	1	215	32	50
157	44	41	2	626	46	50
158	50	24	3	634	55	50
159	50	35	2	940	55	50
160	48	30	2	845	53	55
161	24	50	1	362	47	50
162	35	14	1	294	39	40
163	34	50	4	1524	54	60
164	28	15	1	239	37	40
165	31	13	1	250	35	40
166	31	45	6	2030	59	50
167	33	45	2	495	51	60
168	19	45	1	219	32	50
169	28	50	2	465	47	60
170	16	50	1	346	46	60
171	54	50	3	999	47	60
172	64	50	4	1208	43	60
173	24	23	1	324	46	50
174	22	28	1	158	27	50
175	22	20	1	225	43	40
176	70	45	4	1178	61	50
177	78	53	4	1257	54	55
178	68	50	4	1477	53	60
179	39	25	7	3570	55	65
180	32	25	1	265	32	50
181	32	25	1	265	32	50
182	30	20	1	272	38	40
183	40	30	2	548	40	50
184	34	20	1	333	42	40
185	60	30	2	823	55	50
186	53	30	2	1009	64	50
187	54	26	2	753	60	50
188	28	30	2	485	56	40
189	62	30	2	511	40	40
190	28	25	1	317	48	45
191	20	12	1	160	24	25

trips in a day for various routes are in the range of 9 to 263. Generally the number of trips is less for longer routes and is more for shorter routes in central business district and other high density areas. The trip travel time for various routes is in the range of 15 minutes to 65 minutes and in the walled city area (C.B.D. area) the travel time is higher for the same distance than other areas due to the low speeds (5 kmph).

The number of buses operating on each route in a day is in the range of 1 to 10. This number depends on the frequency and round trip time for a route. The daily average traffic income on each route is in the range of Rs. 4636 to Rs. 69.

By studying the load factors for various routes, routes can be classified on load factor criterion (Table 3.4). The load factor is an important indicator for measuring the efficiency of the existing route pattern. The expenditure and revenue break even at 62 percent whereas operating cost and revenue break even at 45 percent. The low value of break even load factor is largely due to a well balanced fare structure.

Table 3.4 indicates that nearly 35 percent of the existing routes operate below the economical value.

TABLE 3.4 : CLASSIFICATION OF ROUTES BY LOAD FACTORS

Sl.No.	Load Factor Percentage	Number of Routes	Percent
1	Less than 45	66	35
2	45 to 62	107	56
3	62 and above	18	9
Total		191	100

3.4.2 Trip Distribution

The model developed in this study needs the volume of the distribution of trips between various nodes. The A.M.T.S. has not collected origin-destination survey to obtain the trip distribution. The desired O - D matrix is generated, based on the available information of routes, in following steps:

- (i) Average link volume on each route during the day is obtained from load factor and maximum fare criteria.

- (ii) Each stop on a route is assigned a weight depending upon the importance of the stop quantitatively measured in terms of number of routes touching the stop. These weights are used to define the probability of trip generation on each stop of the route.
- (iii) The generated trips at a stop are then distributed to other stops of the route using the relative weights of the different stops.
- (iv) The trip distribution matrix for the network is obtained by combining the distribution of all the routes.

The various steps of this procedure are explained in the following sub-sections.

Average Link Volume on Each Route: The daily volume of passengers served by each route is not available from the A.M.T.S. records. However, daily income of a route, fare between the different stops and load factor of the route are obtained. The expected average link volume on each route is first obtained using the load factor and maximum fare criteria:

(a) **Load Factor Criterion:** The daily average link volume on each route is obtained by the following relation:

$$(VOLP1)_i = (TRIPS)_i * (LF)_i * (CAP) \quad (3.1)$$

where

$(VOLP1)_i$ = Average link volume on route i by load factor criterion.

$(TRIPS)_i$ = Number of scheduled bus trips in a day for route i .

$(LF)_i$ = Average link load factor for route i .

(CAP) = Maximum number of passengers that can be accomodated in a bus (60).

(b) Maximum Fare Criterion: The daily average link volume on each route is obtained by the following relation:

$$(VOLP2)_i = \frac{(INCOME)_i}{(MAXF)_i} \quad (3.2)$$

where

$(VOLP2)_i$ = Average link volume on route i by maximum fare criterion.

$(INCOME)_i$ = Daily average traffic income in paise for a route i .

$(MAXF)_i$ = Maximum fare in paise for a route i .

The load factor criterion is a good estimate for the link flow provided the load factor for each link is used. The average link load factor as obtained from the records is not a very good estimate in situation where there are large variation in load factors of the various links. The average link volume is then also calculated

using the income from the route and the maximum fare on the route. The link volume obtained from these two different criterion are quite close in heavily travelled routes. The maximum fare criterion gives higher link volume in case of longer routes where as load factor criterion gives higher link volume for shorter routes. Due to the variations in the link volume obtained by these two criteria, the maximum of the two is taken for further analysis. The average flow on a link for each direction of a route is taken to be half of the total link flow.

Trip Generation at Various Stops of the Route: The volume of passengers on a link for a particular direction are destined for one of the remaining stops of the route. The major stops attract more passengers than the minor stops. It is desirable that to distribute the trips to various stops, some weightage be assigned to them. The importance of a stop can be judged in terms of the routes passing through it. The number of such interested routes for each stop of a route in a particular direction are determined. Using the number of interested routes for each stop, the probabilities of getting down at different stops are estimated. Let NR_1, NR_2, \dots, NR_n be the number of interested routes touching the stops $1, 2, 3, \dots, NONODS$ for a particular direction of a route.

The flow on a link (i-j) i.e. $(\text{FLOW})_{i-j}$ is distributed among the remaining stops of the route i.e. j, j+1,, NONODS. The probability of a passenger to get down at any of these stops is given by

$$(\text{Prob})_k = \frac{(\text{NR})_k}{\sum_{k=j}^{\text{NONODS}} \text{NR}_k} \quad (3.3)$$

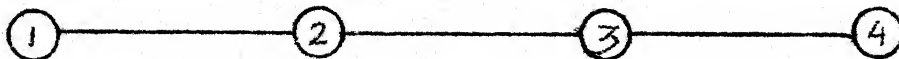
where

$(\text{Prob})_k$ = Probability of a passenger to get down at the stop k of a route.

NR_k = The number of interested routes touching the stop k of a route.

NONODS = Number of stops in a route.

The number of passengers destined for various stops of the route are thus estimated using the above probabilities. It is assumed that the volume of passengers produced at the stop is same as that attracted to it. A sample calculation for one route is given below:



The nodes touched by a route are 1-2-3-4. The number of interested routes for each of this node (stop) are 57, 6, 10 and 31. The link flow of passengers in one direction is 5444. The trip generation at various stops 2, 3 and 4 for direction (1-4) is obtained in the following way:

$$(\text{Prob})_2 = \frac{6}{6 + 10 + 31} = \frac{6}{47}$$

$$(\text{Prob})_3 = \frac{10}{6 + 10 + 31} = \frac{10}{47}$$

$$(\text{Prob})_4 = \frac{31}{6 + 10 + 31} = \frac{31}{47}$$

Let $(\text{TRIPSG})_i$ be the number of trips generated at the stop i . The flow on a link (1,2) (i.e. 5444) is distributed among the remaining stops 2, 3 and 4.

$$(\text{TRIPSG})_2 = (5444) * \frac{6}{47} = 695$$

$$(\text{TRIPSG})_3 = (5444) * \frac{10}{47} = 1158$$

$$(\text{TRIPSG})_4 = (5444) * \frac{31}{47} = 3591$$

The trips generated at the stop 2 i.e. 695 is distributed among the remaining stop 3 and 4 in the similar way. The total trips (column total) generated at the stop 3 has to

to to stop 4. In this way the upper triangle of the trip matrix is derived. The bottom triangle is derived similarly by considering the other direction (4-1).

The result of the above calculations in a form of a matrix are given in Table 3.5.

TABLE 3.5 : TRIP DISTRIBUTION MATRIX FOR A ROUTE

D 0	1	2	3	4
	1	2	3	4
1	-	695	1158	3591
2	518	-	170	525
3	674	71	-	1328
4	4252	447	745	-

Origin-Destination Matrix: The trip distribution matrices of all the 191 routes are combined to find the O-D matrix for the entire network.

The traffic flow volume data used in the analysis is for the year 1979 and it needs to be updated for the year, 1982. The A.M.T.S. records shows that the annual average growth of passenger traffic is 12.6 percent.

Using this uniform growth the O-D matrix for the city is updated for 1982 and is given in Appendix II. The two most important major generators are Lal-darwaja and Kalupur which generates 1, 08, 371 and 1, 12, 102 trips respectively.

3.4.3 Riding Time on Links

For the concentration of link flows on the network, the riding times on various links need to be estimated. The riding time on a link depends upon the characteristics of the link like width, traffic volume its composition, and various traffic control measures on the link. Riding times are not available from the A.M.T.S. records but the travel time of the bus on a route is available. The total riding time of a route r i.e. $(TRT)_r$ is estimated using the following relationship:

$$(TRT)_r = (TT)_r - (TST)_r \quad (3.4)$$

$$(TST)_r = \sum_{j=1}^{NONODS-1} (ST)_j \quad (3.5)$$

where

$(TRT)_r$ = Total riding time on route r .

$(TT)_r$ = Total travel time in one direction for route r .

$(TST)_r$ = Total service time in one direction for route r .

$(ST)_j$ = Service time (dwelling time) at the j^{th} stop of the route.

The service time of passengers at a stop for a bus comprises of boarding time, alighting time and booking time. At most of the stops, it has been observed that the buses are allowed to depart before the tickets are issued. Hence, it is not necessary to include the booking time in reckoning with service times. It has also been observed that there are two doors with boarding and alighting operations taking place simultaneously. Based on the observations of service times made in Kanpur at different stops, Dhingra (1980) has established the following relationship for the service times:

$$y = 6.911 + (2.2525)X \text{ for } X > 0 \quad (3.6)$$

where

y = Alighting time in secs.

X = Number of passengers alighting.

The total service time $(TST)_r$ along the route is estimated as follows using Dhingra's relationship (Eqn.3.6).

$$(TST)_r = 6.911 (NONODS-1) + 2.25 \left(\frac{(NUMP)_r}{(BUSTRP)_r} \right) \quad (3.7)$$

where

$(NUMP)_r$ = Number of passengers served by a bus trip of a route r in one direction.

$(\text{BUSTRP})_r$ = Number of bus trips for a route r.

After estimating the total service time for a route r in one direction, the total riding time $(\text{TRT})_r$ is calculated by Eqn. 3.4. The riding time on link i traversed by route r is calculated by the following equation:

$$(\text{RT})_{ir} = (\text{TRT})_r * \frac{(\text{LNGTH})_i}{\sum_{i=1}^{\text{NLINKS}} (\text{LNGTH})_i} \quad (3.8)$$

where

$(\text{RT})_{ir}$ = Riding time on link i traversed by route r.

$(\text{LNGTH})_i$ = Length of link i.

NLINKS = Number of links in a route.

It is observed that there is some variation in riding time obtained for links served by the number of routes. The average value of the riding time is used for further analysis.

3.5 Preparation of Road Network

The routing model discussed in Chapter 2, concentrates the flow on the links. To start with, a network, consisting of links where it is possible for buses to travel, is needed. The existing route network has 492 links (i.e. 246 links in each direction). To this 22 more links are added on which it is possible for the buses to travel.

The resulting network consists of 514 links. The characteristics of various links of the above network like nodes at ends, length, riding time are obtained and given in Table 3.6.

3.6 Concentrating Passenger Flows

3.6.1 General

The routing model estimates where the passengers are expected to travel in the optimal route system. If all the passengers travel along their shortest paths, this would imply a very dispersed route network with low vehicle utilization and many vehicle hours. On the other hand if the vehicles are filled to capacity, this would imply that passengers are concentrated to large flows and thus have to make substantial detours from their shortest paths, with increased riding time for the passengers. To get a reasonable compromise between these two extremes the sum of operation cost and passenger-riding-time cost can be minimized for a fixed desired O-D matrix.

Let RT_i be the riding time on link i and $((LKFLOW)_i)$ is the passenger flow in unit time on link i then the total riding time for all the passengers is $\sum_i (RT_i)((LKFLOW)_i)$ and the total vehicle time for the network is $\sum_i (RT_i)(NOBUS)_i$ where $(NOBUS)_i$ is the number of bus trips to be made in a

TABLE 2.2 CHARACTERISTICS OF BUS TRANSIT NETWORK

LINK NO.	NODES AT	ENDS	RIDING TIME
1	1	2	5.25
2	1	12	3.54
3	1	13	4.71
4	1	25	3.74
5	1	30	2.90
6	1	66	5.65
7	1	80	3.14
8	2	3	3.52
9	2	5	5.70
10	2	12	7.50
11	2	80	3.47
12	3	4	3.95
13	3	5	4.23
14	3	10	2.30
15	4	9	4.46
16	4	10	3.01
17	4	24	7.57
18	4	42	5.06
19	4	54	6.70
20	4	77	3.74
21	4	6	2.00
22	5	10	3.68
23	5	11	2.92
24	5	41	3.56
25	5	50	8.91
26	5	57	5.12
27	5	65	16.65
28	5	11	2.85
29	6	19	5.59
30	6	33	4.13
31	6	65	9.29
32	6	80	6.97
33	6	106	6.68
34	7	8	2.73
35	7	9	5.72
36	7	13	4.50
37	7	14	4.34
38	7	26	4.19
39	8	9	2.51
40	8	14	5.26
41	8	25	6.51
42	8	30	4.84
43	8	77	7.81
44	8	114	1.93
45	9	30	6.01
46	9	42	3.85
47	10	57	2.50
48	11	12	2.15
49	11	41	2.97
50	11	33	2.90
51	12	14	10.99
52	12	25	5.47

contd.....

TABLE 3.6 (contd.)

LINE NO.	CODES	AT	ENDS	RIDING TIME
53	13		66	4.16
54	14		15	2.84
55	15		16	1.36
56	15	1	10	5.70
57	16		76	5.22
58	17		12	4.73
59	17		38	3.28
60	17		39	3.13
61	17		40	2.71
62	17		49	5.45
63	17		60	6.06
64	18		19	7.64
65	18		34	5.88
66	18		35	2.16
67	18		38	4.59
68	18		49	5.50
69	19		33	5.28
70	19		34	3.77
71	19		64	5.88
72	20		52	2.53
73	20		57	3.21
74	21	1	107	2.28
75	21	1	108	6.40
76	22		24	4.55
77	22		53	2.79
78	22		96	2.50
79	22	1	108	1.18
80	23		24	3.57
81	23		53	4.99
82	23	1	107	4.64
83	24		96	5.05
84	24	1	112	2.50
85	25		77	3.95
86	26		27	2.27
87	26		93	3.44
88	26		94	4.61
89	26		99	3.12
90	27		28	4.27
91	27		63	6.93
92	27		88	5.67
93	27		94	3.63
94	27		99	3.14
95	27		100	4.65
96	28	1	22	3.24
97	28		88	7.10
98	28		88	4.32
99	28		88	3.90
100	28		90	6.10
101	29		33	4.05
102	29		61	2.89
103	29		82	4.26
104	31		32	3.15

contd....

TABLE 3.6 (contd.)

LINK NO.	NODES	AT	ENDS	RIDING TIME
115	31	73		4.64
116	32	33		5.74
117	32	57		3.54
118	32	75		3.41
119	32	78		2.74
120	32	61		2.21
121	32	95		4.13
122	33	41		8.81
123	33	64		11.50
124	33	95		5.68
125	33	78		5.57
126	33	140		13.14
127	34	39		3.38
128	34	40		5.13
129	34	41		4.32
130	34	50		5.03
131	35	36		5.55
132	36	40		2.69
133	40	41		5.70
134	40	50		5.50
135	40	60		9.66
136	40	106		6.24
137	41	50		5.36
138	41	106		2.20
139	42	43		3.53
140	42	56		5.35
141	42	58		7.64
142	43	44		3.14
143	43	45		4.05
144	43	58		3.73
145	44	46		7.21
146	45	56		3.68
147	45	58		3.27
148	46	62		2.80
149	46	47		6.74
150	47	59		2.38
151	47	48		8.70
152	47	59		8.49
153	47	62		16.00
154	48	117		13.35
155	49	60		4.15
156	50	51		2.83
157	50	57		6.17
158	50	60		3.65
159	50	103		4.40
160	50	106		4.34
161	51	52		2.96
162	51	53		4.88
163	51	61		4.69
164	51	103		4.76
165	52	135		6.43
166	52	53		5.39

contd...

TABLE 3.6 (contd.)

STATION	CODES AT	ENDS	RIDING TIME
157	55	57	5.57
158	55	97	2.00
159	55	109	2.56
160	55	57	3.24
161	55	96	3.27
162	55	97	1.00
163	55	109	5.39
164	55	109	3.26
165	55	130	4.61
166	55	130	3.32
167	55	56	2.59
168	55	62	3.71
169	55	112	3.32
170	55	62	4.40
171	55	102	4.78
172	55	59	7.98
173	55	76	3.68
174	55	76	3.05
175	55	120	7.29
176	55	61	4.38
177	55	135	2.27
178	55	135	4.60
179	55	136	3.49
180	55	63	6.99
181	55	74	4.33
182	55	117	11.30
183	55	65	6.25
184	55	139	4.60
185	55	75	7.42
186	55	86	2.67
187	55	95	1.16
188	55	68	5.25
189	55	69	8.59
190	55	72	4.90
191	55	71	5.55
192	55	78	2.49
193	55	73	2.92
194	55	141	4.64
195	55	88	8.86
196	55	95	1.21
197	55	114	2.89
198	55	120	5.99
199	55	80	12.20
200	55	82	2.55
201	55	88	1.55
202	55	82	9.06
203	55	86	3.16
204	55	137	2.15
205	55	83	4.81
206	55	89	1.87
207	55	90	4.25
208	55	98	6.04

contd...

TABLE 3.6 (contd.)

STATION	NODES	AT	NODES	RIDING TIME
200	83	84	3.99	
201	83	104	3.38	
202	84	85	3.29	
203	84	100	2.65	
204	84	101	3.47	
205	84	102	3.30	
206	85	101	3.70	
207	86	87	2.82	
208	86	93	6.05	
209	87	137	3.29	
210	88	137	2.44	
211	89	90	3.99	
212	89	98	6.40	
213	89	102	11.82	
214	90	93	2.60	
215	90	104	4.26	
216	91	92	4.46	
217	91	137	5.11	
218	92	94	3.03	
219	94	95	2.34	
220	96	108	5.81	
221	99	100	3.19	
222	99	102	2.49	
223	99	110	3.27	
224	100	105	6.41	
225	102	105	7.23	
226	107	108	3.03	
227	107	119	4.87	
228	109	135	11.18	
229	110	111	4.43	
230	110	120	6.76	
231	111	142	2.61	
232	112	113	1.86	
233	113	119	8.44	
234	113	138	4.40	
235	117	118	1.23	
236	117	138	7.64	
237	120	121	5.32	
238	120	125	4.76	
239	121	122	11.82	
240	121	123	5.73	
241	121	124	8.56	
242	121	132	7.66	
243	122	123	7.38	
244	122	132	1.93	
245	123	124	3.76	
246	123	132	5.47	
247	130	133	4.05	
248	130	134	8.26	

unit time on a link i . The objective function is

Minimize

$$Z_1 = \left(\sum_i (RT_i) \right) (LKFLOW)_i + \sum_i RT_i (NOBUS)_i W \quad (3.9)$$

subject to all demand of travel matrix is satisfied.

where

W = Value of vehicle time compared to riding time of passenger.

$(NOBUS)_i$ and W are to be estimated using the available data of the bus transit system.

3.6.2 Estimation of Parameters

(a) Number of Bus Trips on a Link: The number of trips to be made in a unit time on a link i i.e. $((NOBUS)_i)$ depends upon the passenger flow on that link $((LKFLOW)_i)$. Some studies (Scott, 1969; Rea, 1971) indicate that $((NOBUS)_i)$ is directly proportional to the square root of passengers on a link. In the absence of any such like relationship for the Indian cities, the following procedure is adopted to establish the relationship:

- (i) The average link flow of passengers on a route for all the 191 routes as obtained in Section 3.4 is related with the existing number of bus trips on that route.

- (ii) The regression analysis is carried out for all the 191 routes and the following relationship is estimated.

$$(\text{NOBUS})_i = 0.137 ((\text{LKFLOW})_i)^{0.795} \quad (3.10)$$

$$(R^2 = 0.88)$$

where

$(\text{NOBUS})_i$ = Number of bus trips to be made in a unit time on a link i .

$(\text{LKFLOW})_i$ = Flow of passengers in unit time on link i .

(b) Value of Vehicle Time Compared to Passenger Riding Time (W): To get the value of W, passenger riding and vehicle operating cost are calculated. Riding time cost can be determined using indifference curves (or utility theory) for the set of passengers under consideration. In that case surveys have to be conducted to establish the riding time cost models. But such detailed analysis is not made and it is assumed that the captive users with the income range of Rs. 7200.00 to Rs. 9600.00 per annum are constituting the demand for bus transit. To be conservative a sum of Rs. 7200.00 per annum is taken as the basis for calculating the monetary value of time. Assuming 25 working days in a month and 8 working hours per day, the value of time is thus Rs. 3.00 per hour.

The operating cost of a vehicle (including capital cost) is taken as Rs. 2.5 per vehicle kilometre (Namballa, 1982) i.e. $KMCOST = Rs. 2.5$ for a bus with 60 seat capacity.

The kilometres travelled by a bus per hour (BUSKMH) considering all the 191 routes are calculated using two criteria: (i) with consideration of the service time at the stops of a route (ii) without consideration of service time at the stops of a route (i.e. bus goes directly from origin to terminal). The values of BUSKMH are shown in Table 3.7.

TABLE 3.7 : AVERAGE OPERATING SPEED OF BUSES IN
AHMEDABAD

Sl.No.	Criteria	Mean value of (BUSKMH)KMS	Median Value of (BUSKMH)KMS
1	Service time considered	16.51	15.93
2	Service time not considered	17.93	16.99

With these four values of BUSKMH, the four values of W are calculated as follows:

$$W = (BUSKMH) * (KMCOST) / (VT) \quad (3.11)$$

where

BUSKMH = Kilometres travelled by a bus in one hour.

KMCOST = Operating cost of a vehicle(bus) per bus kilometre.

VT = Value of riding time (i.e. Rs.3/hr.).

From the values of W, the mean value of W is taken as 15. This indicate that the value of vehicle time is 15 times that of the passenger riding time.

3.6.3 Minimizing the objective function

The objection function Eqn. 3.9 can be written as

$$\sum_i (RT)_i (LKFLOW)_i + \sum_i (RT)_i \cdot (0.137) (LKFLOW)^{0.795} \cdot (15) \quad (3.12)$$

after substituting the values of $((NOBUS)_i)$ i.e.

$0.137((LKFLOW)_i)^{0.795}$ and W i.e. 15 from the Equations 3.10 and 3.11 respectively so, the objective function is

$$\begin{aligned} \text{Minimize} \\ Z_1 = \sum_i (LKFLOW)_i (RT)_i \left(1 + \frac{1.0275}{((LKFLOW)_i)^{0.205}} \right) \end{aligned} \quad (3.13)$$

$$= \sum_i (LKFLOW)_i T_i^*$$

where

$$T_i^* = (RT)_i \left(1 + \frac{1.0275}{(LKFLOW)_i^{0.205}} \right) \quad (3.14)$$

To obtain the minimum value of the nonlinear objective function (Eqn. 3.13) defined earlier the heuristic algorithm given in section 2.6.2 is used. As described earlier, backward approach (i.e. deleting links from a fine meshed network) appear to give better results than the forward approach (i.e. adding links to the minimal spanning tree). For the case study network, a backward approach is chosen. To start with all the 514 links are taken and then proceed towards to the coarse-meshed one (402 links). For this case study, four networks are tested. The heuristic algorithm is used for each of the four different networks to obtain the total cost in terms of time. A brief summary of this algorithm as applied to the networks is as follows:

- (i) The shortest paths for all the origin-destination pairs are obtained. In the first iteration, only riding time (RT_i) is considered but in subsequent iterations the sum of riding and vehicle time (as revised in the subsequent steps) i.e. T_i^* is used. Using the shortest paths, all the link flows $(LKFLOW)_i$ are estimated for the given O-D matrix.
- (ii) The time (T_i) to tranerse a link i is revised (T_i^*) based on the link flow $((LKFLOW)_i)$ using the following relationship:

$$T_i^* = (RT)_i * \left(1 + \frac{1.0275}{(LKFLOW)_i^{0.205}} \right) .$$

- (iii) The revised time T_i obtained in Step (ii) is used to find the shortest paths for all the O-D pairs and revised value of the link flow $(LKFLOW)_i^*$ is obtained.
- (iv) Compute the total link time i.e. $LT_i = (T_i)^* (LKFLOW_i^*)$ and total time for the network i.e.

$$TLT = \sum_i (T_i)^* ((LKFLOW)_i^* .$$
- (v) If any of the link time (i.e. LT_i) or total link time (TLT) gets changed in Step (iv) then the procedure is repeated starting with Step (ii) otherwise it is stopped.

The above procedure is repeated for all the four different networks and it is observed that generally about four iterations need to be performed for each of the network to obtain the convergence of the total link time. As the network is quite large for the case study only one iteration is performed in one run of the experiment. The results obtained from an iteration are given as the input for the next iteration. The CPU time on DEC 1090 system for the iteration of a network is about 4 minutes. 16 different runs are made and the results are shown in Table 3.8. For the network number 2, 3 and 4 those links

having much less flow are deleted. The results indicate that by deleting some links from the starting network (no. 1 having 514 links), the total time gets reduced upto a certain stage and then starts increasing. The results indicate that the minimum time is for the network number 3 having 426 links. This network is considered for the further analysis.

TABLE 3.8 : CONCENTRATION OF PASSENGER FLOWS IN
ALTERNATIVE NETWORKS

Sl. No.	Number of links in a net- work	ITERATION			
		1	2	3	4
		Total riding time	Total (riding+ vehicle) time	Total (riding+ vehicle) time	Total (riding + vehicle) time
1	514	11897919	13704568	13718200	13720158
2	492	11898220	13705189	13718554	13720282
3	426	11903306	13723576	13717526	13717565
4	402	11954794	13773298	13767130	13773238

3.7 Generation of Routes

3.7.1 General

The model specifies that a large set of all possible routes be generated and then optimal ones alongwith their

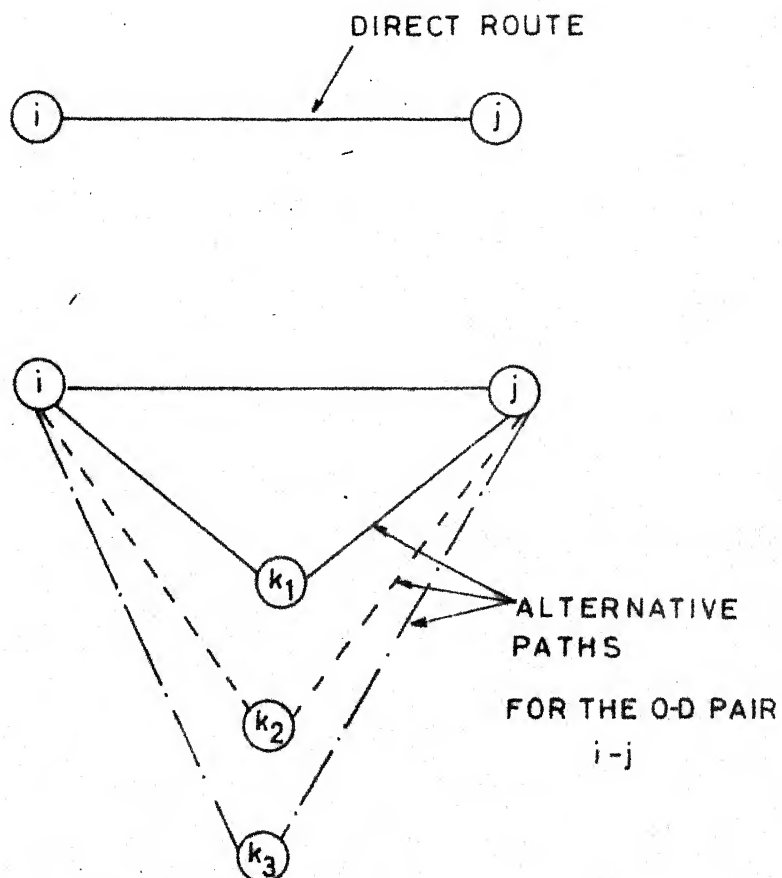
frequencies be selected using Linear Programming, so that the number of transfers saved are maximized. For a large network as taken in this study, theoretically there may be a very large number of possible routes between every O-D pair, but some of which may not be feasible. Rather than eliminating the nonfeasible routes at a latter stage, an heuristic procedure is developed to generate sufficiently large number of routes which satisfy certain practical constraints. The following requirements are specified:

- (i) The length of the route should not be less than 2.0 kms as otherwise it may result in concentration of the buses in some sections of the network.
- (ii) The path of the route between two terminating stations should not meander excessively from the shortest path. The length of the path of a route should not be greater than the twice the shortest distance between the termini.
- (iii) There should not be any backtracking on the route.

In cases where there are a number of intermediate stations on the shortest path between two termini, there may be a very large number of alternative paths which may be formulated. It is desirable that the nodes inserted in between be selected rationally without leaving the combinations that satisfy the basic requirements. If all

connected by a link $i-j$. Alternative paths for this route between i and j can be found out by inserting the intermediate nodes (say k) such that path $i-k-j$ satisfies the requirements namely the length of the path $i-k-j$ is less than twice the shortest distance between nodes i and j (Fig. 3.3). In this way all possible intermediate nodes $K (k_1, k_2, \dots)$ that can be inserted are analyzed and all the resulting routes between i and j are used while generating the routes between the distant termini.

- (ii) The O-D pairs not directly connected are divided into various groups according to the shortest distance through them. In this study, the O-D pairs are divided into 9 different groups starting with 1.5 Kms. and ending with 20 Kms. The generation of the routes is first done for the closer O-D pairs and then expanded by using the information of already generated routes. In one experiment run one group is taken for the generation.
- (iii) For a given group of O-D pairs the alternative paths of the route are generated as follows:
Let $i-j$ be the O-D pair having stops i_1, i_2, i_3, \dots etc.



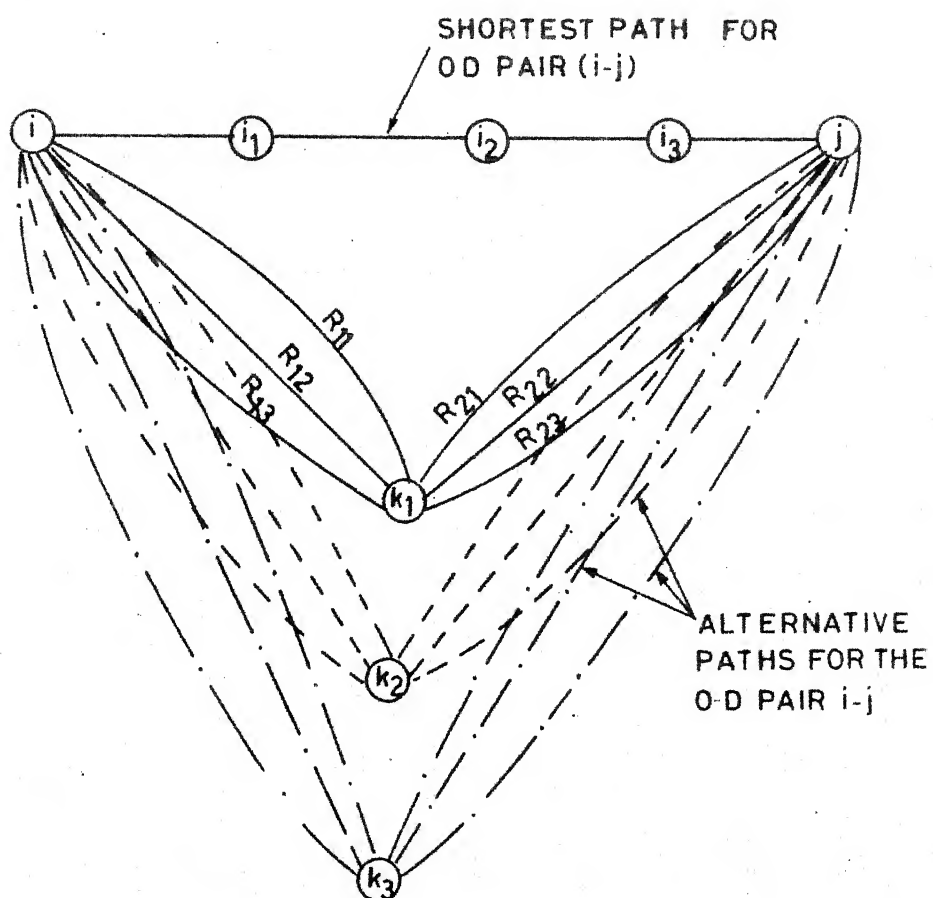
IF $SD(i, k) + SD(k, j) \nless 2.0 * SD(i, j)$
 THEN NODE $k (k = k_1, k_2, k_3, \dots)$ IS
 INSERTED OTHERWISE NOT.

**FIG.33 ALTERNATIVE PATHS FOR DIRECTLY
 CONNECTED O-D PAIR.**

on the shortest path between them. Let K_1 be the node to be inserted such that the shortest path between i and j via K (i.e. $SD(i,K) + SD(K,j)$) is less than 1.5 times the shortest distance between i and j ($SD(i,j)$). All the previously established routes between i and k_1 (i.e. $R_{11}, R_{12}, R_{13}, \dots$) and between k_1 and j (i.e. $R_{21}, R_{22}, R_{23}, \dots$) are considered (Fig.3.4). All the combinations of the routes between i to k_1 and k_1 to j are analyzed such that the total length of the selected path between i to j does not exceed twice the shortest distance between i and j .

This procedure is repeated for all the possible intermediate nodes (i.e. k_1, k_2, k_3, \dots) to be inserted and all the feasible routes are stored.

- (iv) The above procedure (i.e. step iii) is repeated for all the O-D pairs of a group.
- (v) As the distance between the O-D pair increases it is not appropriate to select all the O-D pairs as terminals and those having less demand may be neglected as otherwise it considerably increases the computation. For the O-D pairs which are more than 7 kms. away and have trip distribution of less than 500 passengers per day are not considered in generation of routes at this stage. The procedure



IF $SD(i,k) + SD(k,j) \nlessgtr 1.5 * SD(i,j)$
 THEN NODE $k(k=k_1, k_2, k_3 \text{ --- })$ IS
 INSERTED OTHERWISE NOT.

FIG.3.4 ALTERNATIVE PATHS FOR NOT DIRECTLY
 CONNECTED O-D PAIR.

given in steps (iii) to (v) is repeated for all the groups.

- (vi) All the routes generated are used to find if any traffic demand for a O-D pair is left out. If it is so, new routes are generated between these O-D pairs.

In a nutshell, the procedure is as follows:

- (a) Routes are first generated for the O-D pair which have direct links.
- (b) The O-D pairs which are not directly connected are divided into various groups according to shortest distance between them. The generation of routes is done by first analyzing closer O-D pairs and then expanding for distant O-D pairs (shortest distance less than 7 kms.).
- (c) The node (K) is inserted between the O-D pair(i-j) such that the distance of the selected path i-k-j **does not** exceed twice the shortest distance between i and j.
- (d) For distant O-D pairs (shortest distance greater than 7 kms.), only major O-D pairs are selected for route generation. Alternative paths between these pairs are generated.

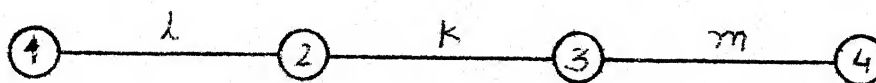
- (e) New Routes are generated for the unsatisfied demand of the O-D pairs.

The heuristic procedure gives 457 possible routes for the network, the path of these routes and their lengths are given in Appendix III.

3.8 Transfers Saved on a Route

The model evaluates the generated set of routes in previous section by the criterion of maximum number of transfers saved by a route through a LP formulation. So for each node of a route, turning flow between the links and the number of transfers saved for this turning flow is needed. The total number of transfers saved by a route is the sum of the transfers saved by each node of a route.

The number of transfers saved per route trip is calculated in the following way:



Let the path of a route be represented by the nodes 1, 2, 3 and 4 and links l, k and m as shown above. Let

$(\text{TURNFL})_{lk}$ be the number of passengers per day going directly from link l to link k or vice versa. The estimated number of bus trips per day is $(\text{NOBUS})_l$ on link l . If a route goes directly from link l to link k the number of transfers saved per route trip for this route and this turning flow, is estimated by following relationship:

$$(\text{NOTRAN})_{pr} = \frac{(\text{TURNFL})_{lk}}{\text{Minimum} \left\{ (\text{NOBUS})_l, (\text{NOBUS})_k \right\}} \quad (3.15)$$

where

$(\text{NOTRAN})_{pr}$ = Number of transfers saved for p^{th} turning flow of route r .

$(\text{TURNFL})_{lk}$ = Number of passengers travelling from link l to link k or vice versa.

$\text{Minimum} \left\{ (\text{NOBUS})_l, (\text{NOBUS})_k \right\}$ = The minimum value of the number of bus trips on the two links l and k .

The various steps for calculating the number of transfers saved by a route trip are as follows:

- (i) Calculate the turning flow at a node i ($(\text{TURNFL})_{lk}$) i.e. the number of passengers per day going directly from link l to link k or vice versa by the following relationship:

$$(\text{TURNFL})_{lk} = \sum_{t=i+1}^{\text{NONODS}} \sum_{s=1}^{i-1} (\text{JFLOW}(s, t)) \quad (3.16)$$

where

$JFLOW(s,t)$ = Flow of passengers between the O-D pair s-t.

i = Node of a link where links l and k intersect.

$NONODS$ = Number of nodes in a route.

- (ii) Estimate the number of bus trips in each direction on the links of a route using the following relationship:

$$(NOBUS)_l = 0.137 ((LKFLOW)_l)^{0.795} \quad (3.17)$$

The link flow on link l i.e. $(LKFLOW)_l$ connecting the nodes i and j , is found out by following relationship:

$$(LKFLOW)_l = \sum_{t=i+1}^{NONODS} \sum_{s=1}^i JFLOW(s,t) \quad (3.18)$$

The value of $JFLOW(s,t)$ is obtained from the O-D matrix.

- (iii) After getting the values of $(TURNFL)_{lk}$ and $(NOBUS)_l$ from the steps (i) and (ii) respectively, the number of transfers saved at each node of a route is estimated by the Eqn. 3.15.
- (iv) The number of transfers saved is calculated for each turning flow along the route and added to the total for the route, to obtain the total number of transfers saved by a route $(TTRAN)_r$.

In a nutshell, the procedure is as follows:

- (1) All turning flows are found out along the route using O-D matrix.
- (2) The number of bus trips on each link is estimated using the relationship between link flow and the number of bus trips. The link flow is found by using O-D matrix.
- (3) The number of transfers saved for each turning flow per route trip is found out as the ratio of the turning flow and the minimum number of bus trips on the two links which intersect at the node.
- (4) The total number of transfers saved by a route $(TTRAN)_r$ is found out by summing the transfers saved for each turning flow along the route.

The above procedure is used for the network for the case study and number of transfers saved by each of the 457 routes are obtained. For each route, the transfers saved are calculated along the route and added to get the total number of transfers saved. Then all turning movements on the network are identified. The different values of the $p_{i,j}^{th}$ turning movement are obtained for various routes. From these, the maximum value of the $p_{i,j}^{th}$ turning movement is found out. For this network 421 turning movements and

their maximum values are found out. The number of transfers saved by each route is shown in the Appendix III.

3.9 Maximum Frequency on a Route

For the LP problem formulation, described in the Chapter 2, the maximum frequency i.e. $(MAXFRE)_r$ is required for every route for the constraint set of equations. The bus trips on every link of a route is estimated using Eqn. 3.9 and maximum frequency of the route is estimated.

3.10 Simultaneous Choice of Routes and Frequencies

In the preceding phases passengers have been assigned paths considering passenger riding time cost and operation cost. A set of interesting routes (457) has also been generated. In this phase optimal set of routes and their frequencies are obtained such that as many transfers as possible are avoided. The problem is formulated and solved as a linear-programming problem(LP).

The objective function as described in Chapter 2 is

$$\text{Maximize } Z = \sum_{r=1}^{NR} (TTRAN)_r (FREQ)_r \quad (3.19)$$

subject to four sets of constraints

$$(i) \quad \sum_{r=1}^{NR} (NOTRAN)_{pr} \cdot (FREQ)_r \leq (MAXTFL)_p \quad \forall_p \quad (3.20)$$

$$(ii) \quad \sum_{r=1}^{NR} (RTIME)_r \cdot (FREQ)_r \leq (OT) \cdot (OPF) \quad (3.21)$$

$$(iii) \quad 0 \leq (FREQ)_r \leq (MAXFRE)_r \quad \forall_r \quad (3.22)$$

$$(iv) \quad (NOTRN)_p \geq 0 \quad \forall_p \quad (3.23)$$

where

$(NOTRN)_{pr}$ = Number of transfers saved for p^{th} turning flow of route r .

$(FREQ)_r$ = Frequency on route r

$(TTRAN)_r$ = Total number of transfers saved by a route r .

NR = Number of routes in a network

$(MAXTFL)_p$ = Maximum value of the turning flow for the p^{th} turning movement.

$(RTIME)_r$ = Round trip time on route r .

$(MAXFRE)_r$ = Maximum frequency of route r .

$(NOTRN)_p$ = Number of transfers saved for the p^{th} turning flow.

OPF = Operating fleet size.

OT = Operating time in hrs.

For the case study network, 457 routes have been generated and 421 turning movements (flows) are indentified. This results into 879 constraint equations. For the LP solution the work vector dimension requirement is

$(M1 + M2 + 2) * (M1 + M2 + 2) + 3 * M1 + 2 * M2 + 4$ where $M1$ is the number of inequality constraints (=879) and $M2$ is the number of equality constraints. Beside work vector

dimension, other memory storage is also required for the coefficient matrices and resource vector. It is found that the available 'DEC-1090 SYSTEM' is not in a position to handle the solution of LP of such a large magnitude due to the core capacity. To tackle this problem, LP solution is done in parts by dividing the network into seven distinct parts keeping in mind the interaction of the various parts.

For the case study network, the values of $(NOTRAN)_{pr}$, $(TTRAN)_r$, $(MAXTFL)_p$ and $(MAXFRE)_r$ are already calculated in the previous sections for all the 457 routes.

The $(RTIME)_r$ i.e. round trip time on a route r is calculated by the following formula:

$$(RTIME)_r = \frac{(TRL)_r}{AVERSP} + (LOT)_r \quad (3.24)$$

where

- $(TRL)_r$ = Total route length (Kms.)
- $AVERSP$ = Average speed of the bus (Kmph.)
- $(LOT)_r$ = Lay over time at the destination of a route r .

The average speed of the bus is estimated using the values of different speeds in different areas of the city. The speeds of the bus are in the range of 5-10 Kmph, 10-20 Kmph. and 20-25 Kmph for walled city, intermediate and peripheral and outlying areas respectively. So, the average

speed of the bus is taken as 15 Kmph.

The lay over time at the destination of a route is estimated taking into consideration the route length. For a route length less than 5 Kms., 5-15 Kms. and greater than 15 Kms., the lay over time is taken as 5 min, 10 min and 15 min respectively.

The constraint set (ii) makes use of the operating fleet size. Experiment runs are made with three different operating fleet sizes (670, 750, 790). The total fleet of the network is divided among the various parts of the network in proportion with the maximum frequency and round trip time of the routes contained in the part of the network, and it is given as the input to the experimental run.

From the optimal set of routes for each fleet size, the routes having frequency less than 18 (i.e. headway greater than one hour) are deleted. The final set of optimal routes and their frequencies as obtained for the total fleet size of 670 is given in Table 3.9.

3.11 Analysis of Results

For the fixed O-D matrix of Ahmedabad, the model generates 426 links on the network on which the passenger flow can be concentrated so as to minimize the total cost (Riding time cost + Operating vehicle cost). The network

TABLE 3.9 (PART I): PATHS OF OPTIMAL BUS ROUTES FOR AHMEDABAD (OPERATING FLEET = 670)

ROUTE NO	ROUTE LENGTH	NODES TOUCHED BY THE ROUTE	
1	100	41 106	
2	100	41 106	41
3	100	41 106	
4	100	41 106	
5	100	41 106	
6	100	41 106	
7	100	41 106	
8	100	41 106	
9	100	41 106	
10	100	41 106	
11	100	41 106	
12	100	41 106	
13	100	41 106	
14	100	41 106	
15	100	41 106	
16	100	41 106	
17	100	41 106	
18	100	41 106	
19	100	41 106	
20	100	41 106	
21	100	41 106	
22	100	41 106	
23	100	41 106	
24	100	41 106	
25	100	41 106	
26	100	41 106	
27	100	41 106	
28	100	41 106	
29	100	41 106	
30	100	41 106	
31	100	41 106	
32	100	41 106	
33	100	41 106	
34	100	41 106	
35	100	41 106	
36	100	41 106	
37	100	41 106	
38	100	41 106	
39	100	41 106	
40	100	41 106	
41	100	41 106	
42	100	41 106	
43	100	41 106	
44	100	41 106	
45	100	41 106	
46	100	41 106	
47	100	41 106	
48	100	41 106	
49	100	41 106	
50	100	41 106	
51	100	41 106	
52	100	41 106	
53	100	41 106	
54	100	41 106	
55	100	41 106	
56	100	41 106	
57	100	41 106	
58	100	41 106	
59	100	41 106	
60	100	41 106	
61	100	41 106	
62	100	41 106	
63	100	41 106	
64	100	41 106	
65	100	41 106	
66	100	41 106	
67	100	41 106	
68	100	41 106	
69	100	41 106	
70	100	41 106	
71	100	41 106	
72	100	41 106	
73	100	41 106	
74	100	41 106	
75	100	41 106	
76	100	41 106	
77	100	41 106	
78	100	41 106	
79	100	41 106	
80	100	41 106	
81	100	41 106	
82	100	41 106	
83	100	41 106	
84	100	41 106	
85	100	41 106	
86	100	41 106	
87	100	41 106	
88	100	41 106	
89	100	41 106	
90	100	41 106	
91	100	41 106	
92	100	41 106	
93	100	41 106	
94	100	41 106	
95	100	41 106	
96	100	41 106	
97	100	41 106	
98	100	41 106	
99	100	41 106	
100	100	41 106	

Contd.....

TABLE 3.9 (part 1): (Contd.)

ROUTE NO	ROUTE LENGTH	NODES TOUCHED	BY THE ROUTE
1	100	105	
2	100	129	
3	100	113	
4	100	113	
5	100	113	
6	100	113	
7	100	113	
8	100	113	
9	100	113	
10	100	113	
11	100	113	
12	100	113	
13	100	113	
14	100	113	
15	100	113	
16	100	113	
17	100	113	
18	100	113	
19	100	113	
20	100	113	
21	100	113	
22	100	113	
23	100	113	
24	100	113	
25	100	113	
26	100	113	
27	100	113	
28	100	113	
29	100	113	
30	100	113	
31	100	113	
32	100	113	
33	100	113	
34	100	113	
35	100	113	
36	100	113	
37	100	113	
38	100	113	
39	100	113	
40	100	113	
41	100	113	
42	100	113	
43	100	113	
44	100	113	
45	100	113	
46	100	113	
47	100	113	
48	100	113	
49	100	113	
50	100	113	
51	100	113	
52	100	113	
53	100	113	
54	100	113	
55	100	113	
56	100	113	
57	100	113	
58	100	113	
59	100	113	
60	100	113	
61	100	113	
62	100	113	
63	100	113	
64	100	113	
65	100	113	
66	100	113	
67	100	113	
68	100	113	
69	100	113	
70	100	113	
71	100	113	
72	100	113	
73	100	113	
74	100	113	
75	100	113	
76	100	113	
77	100	113	
78	100	113	
79	100	113	
80	100	113	
81	100	113	
82	100	113	
83	100	113	
84	100	113	
85	100	113	
86	100	113	
87	100	113	
88	100	113	
89	100	113	
90	100	113	
91	100	113	
92	100	113	
93	100	113	
94	100	113	
95	100	113	
96	100	113	
97	100	113	
98	100	113	
99	100	113	
100	100	113	

Contd.....

TABLE 3.9 (Part 1): (Contd.)

ROUTE NO	ROUTE LENGTH	NODES TOUCHED	BY THE ROUTE
1	4	11	1
2	4	17	27
3	4	7	29
4	4	32	31
5	8	34	32
6	13	34	79
7	17	34	88
8	17	34	8
9	17	34	7
10	17	34	26
11	17	34	99
12	17	34	110
13	17	34	121
14	17	34	123
15	17	34	122
16	17	34	121
17	17	34	123
18	17	34	122
19	17	34	121
20	17	34	123
21	17	34	122
22	17	34	121
23	17	34	123
24	17	34	122
25	17	34	121
26	17	34	123
27	17	34	122
28	17	34	121
29	17	34	123
30	17	34	122
31	17	34	121
32	17	34	123
33	17	34	122
34	17	34	121
35	17	34	123
36	17	34	122
37	17	34	121
38	17	34	123
39	17	34	122
40	17	34	121
41	17	34	123
42	17	34	122
43	17	34	121
44	17	34	123
45	17	34	122
46	17	34	121
47	17	34	123
48	17	34	122
49	17	34	121
50	17	34	123
51	17	34	122
52	17	34	121
53	17	34	123
54	17	34	122
55	17	34	121
56	17	34	123
57	17	34	122
58	17	34	121
59	17	34	123
60	17	34	122
61	17	34	121
62	17	34	123
63	17	34	122
64	17	34	121
65	17	34	123
66	17	34	122
67	17	34	121
68	17	34	123
69	17	34	122
70	17	34	121
71	17	34	123
72	17	34	122
73	17	34	121
74	17	34	123
75	17	34	122
76	17	34	121
77	17	34	123
78	17	34	122
79	17	34	121
80	17	34	123
81	17	34	122
82	17	34	121
83	17	34	123
84	17	34	122
85	17	34	121
86	17	34	123
87	17	34	122
88	17	34	121
89	17	34	123
90	17	34	122
91	17	34	121
92	17	34	123
93	17	34	122
94	17	34	121
95	17	34	123
96	17	34	122
97	17	34	121
98	17	34	123
99	17	34	122
100	17	34	121
101	17	34	123
102	17	34	122
103	17	34	121
104	17	34	123
105	17	34	122
106	17	34	121
107	17	34	123
108	17	34	122
109	17	34	121
110	17	34	123
111	17	34	122
112	17	34	121
113	17	34	123
114	17	34	122
115	17	34	121
116	17	34	123
117	17	34	122
118	17	34	121
119	17	34	123
120	17	34	122
121	17	34	121
122	17	34	123
123	17	34	122
124	17	34	121
125	17	34	123
126	17	34	122
127	17	34	121
128	17	34	123
129	17	34	122
130	17	34	121
131	17	34	123
132	17	34	122
133	17	34	121
134	17	34	123
135	17	34	122
136	17	34	121
137	17	34	123
138	17	34	122
139	17	34	121
140	17	34	123
141	17	34	122
142	17	34	121
143	17	34	123
144	17	34	122
145	17	34	121
146	17	34	123
147	17	34	122
148	17	34	121
149	17	34	123
150	17	34	122
151	17	34	121
152	17	34	123
153	17	34	122
154	17	34	121
155	17	34	123
156	17	34	122
157	17	34	121
158	17	34	123
159	17	34	122
160	17	34	121
161	17	34	123
162	17	34	122
163	17	34	121
164	17	34	123
165	17	34	122
166	17	34	121
167	17	34	123
168	17	34	122
169	17	34	121
170	17	34	123
171	17	34	122
172	17	34	121
173	17	34	123
174	17	34	122
175	17	34	121
176	17	34	123
177	17	34	122
178	17	34	121
179	17	34	123
180	17	34	122
181	17	34	121
182	17	34	123
183	17	34	122
184	17	34	121
185	17	34	123
186	17	34	122
187	17	34	121
188	17	34	123
189	17	34	122
190	17	34	121
191	17	34	123
192	17	34	122
193	17	34	121
194	17	34	123
195	17	34	122
196	17	34	121
197	17	34	123
198	17	34	122
199	17	34	121
200	17	34	123

contd.....

TABLE 3.9 (part 1): (Contd.)

ROUTES		NODES		TOUCHED		BY THE		ROUTE	
NO.	LENGTH	1	2	3	4	5	6	7	8
1	7.9	1	1	1	1	1	1	1	1
2	7.9	1	1	1	1	1	1	1	1
3	7.9	1	1	1	1	1	1	1	1
4	7.9	1	1	1	1	1	1	1	1
5	7.9	1	1	1	1	1	1	1	1
6	7.9	1	1	1	1	1	1	1	1
7	7.9	1	1	1	1	1	1	1	1
8	7.9	1	1	1	1	1	1	1	1
9	7.9	1	1	1	1	1	1	1	1
10	7.9	1	1	1	1	1	1	1	1
11	7.9	1	1	1	1	1	1	1	1
12	7.9	1	1	1	1	1	1	1	1
13	7.9	1	1	1	1	1	1	1	1
14	7.9	1	1	1	1	1	1	1	1
15	7.9	1	1	1	1	1	1	1	1
16	7.9	1	1	1	1	1	1	1	1
17	7.9	1	1	1	1	1	1	1	1
18	7.9	1	1	1	1	1	1	1	1
19	7.9	1	1	1	1	1	1	1	1
20	7.9	1	1	1	1	1	1	1	1
21	7.9	1	1	1	1	1	1	1	1
22	7.9	1	1	1	1	1	1	1	1
23	7.9	1	1	1	1	1	1	1	1
24	7.9	1	1	1	1	1	1	1	1
25	7.9	1	1	1	1	1	1	1	1
26	7.9	1	1	1	1	1	1	1	1
27	7.9	1	1	1	1	1	1	1	1
28	7.9	1	1	1	1	1	1	1	1
29	7.9	1	1	1	1	1	1	1	1
30	7.9	1	1	1	1	1	1	1	1
31	7.9	1	1	1	1	1	1	1	1
32	7.9	1	1	1	1	1	1	1	1
33	7.9	1	1	1	1	1	1	1	1
34	7.9	1	1	1	1	1	1	1	1
35	7.9	1	1	1	1	1	1	1	1
36	7.9	1	1	1	1	1	1	1	1
37	7.9	1	1	1	1	1	1	1	1
38	7.9	1	1	1	1	1	1	1	1
39	7.9	1	1	1	1	1	1	1	1
40	7.9	1	1	1	1	1	1	1	1
41	7.9	1	1	1	1	1	1	1	1
42	7.9	1	1	1	1	1	1	1	1
43	7.9	1	1	1	1	1	1	1	1
44	7.9	1	1	1	1	1	1	1	1
45	7.9	1	1	1	1	1	1	1	1
46	7.9	1	1	1	1	1	1	1	1
47	7.9	1	1	1	1	1	1	1	1
48	7.9	1	1	1	1	1	1	1	1
49	7.9	1	1	1	1	1	1	1	1
50	7.9	1	1	1	1	1	1	1	1
51	7.9	1	1	1	1	1	1	1	1
52	7.9	1	1	1	1	1	1	1	1
53	7.9	1	1	1	1	1	1	1	1
54	7.9	1	1	1	1	1	1	1	1
55	7.9	1	1	1	1	1	1	1	1
56	7.9	1	1	1	1	1	1	1	1
57	7.9	1	1	1	1	1	1	1	1
58	7.9	1	1	1	1	1	1	1	1
59	7.9	1	1	1	1	1	1	1	1
60	7.9	1	1	1	1	1	1	1	1
61	7.9	1	1	1	1	1	1	1	1
62	7.9	1	1	1	1	1	1	1	1
63	7.9	1	1	1	1	1	1	1	1
64	7.9	1	1	1	1	1	1	1	1
65	7.9	1	1	1	1	1	1	1	1
66	7.9	1	1	1	1	1	1	1	1
67	7.9	1	1	1	1	1	1	1	1
68	7.9	1	1	1	1	1	1	1	1
69	7.9	1	1	1	1	1	1	1	1
70	7.9	1	1	1	1	1	1	1	1
71	7.9	1	1	1	1	1	1	1	1
72	7.9	1	1	1	1	1	1	1	1
73	7.9	1	1	1	1	1	1	1	1
74	7.9	1	1	1	1	1	1	1	1
75	7.9	1	1	1	1	1	1	1	1
76	7.9	1	1	1	1	1	1	1	1
77	7.9	1	1	1	1	1	1	1	1
78	7.9	1	1	1	1	1	1	1	1
79	7.9	1	1	1	1	1	1	1	1
80	7.9	1	1	1	1	1	1	1	1
81	7.9	1	1	1	1	1	1	1	1
82	7.9	1	1	1	1	1	1	1	1
83	7.9	1	1	1	1	1	1	1	1
84	7.9	1	1	1	1	1	1	1	1
85	7.9	1	1	1	1	1	1	1	1
86	7.9	1	1	1	1	1	1	1	1
87	7.9	1	1	1	1	1	1	1	1
88	7.9	1	1	1	1	1	1	1	1
89	7.9	1	1	1	1	1	1	1	1
90	7.9	1	1	1	1	1	1	1	1
91	7.9	1	1	1	1	1	1	1	1
92	7.9	1	1	1	1	1	1	1	1
93	7.9	1	1	1	1	1	1	1	1
94	7.9	1	1	1	1	1	1	1	1
95	7.9	1	1	1	1	1	1	1	1
96	7.9	1	1	1	1	1	1	1	1
97	7.9	1	1	1	1	1	1	1	1
98	7.9	1	1	1	1	1	1	1	1
99	7.9	1	1	1	1	1	1	1	1
100	7.9	1	1	1	1	1	1	1	1

TABLE 3.3 (PART II) : CHARACTERISTICS OF OPTIMAL BUS ROUTES
(OPERATING FLEET = 670)

NO. OF BUSES PER DAY	NO. OF TRIPS PER DAY	ROUTE TIME (MIN.)	NO. OF BUSES REQD.
1	64	21.8	2
2	20	25.0	1
3	54	21.8	2
4	02	33.5	1
5	28	25.0	1
6	26	24.2	1
7	47	33.6	1
8	25	31.4	1
9	51	31.2	2
10	25	33.5	1
11	23	21.0	1
12	40	25.0	2
13	35	30.4	1
14	57	30.4	2
15	55	21.0	1
16	27	30.4	1
17	25	33.4	1
18	35	30.4	1
19	25	30.4	1
20	35	36.0	2
21	39	21.0	1
22	20	32.8	1
23	56	35.2	3
24	84	35.2	3
25	71	40.8	2
26	54	32.0	3
27	82	31.2	3
28	57	35.2	3
29	62	25.0	3
30	95	32.0	1
31	35	23.4	1
32	57	32.8	1
33	46	36.8	1
34	69	24.2	3
35	64	36.0	3
36	81	24.2	3
37	46	30.4	2
38	31	31.2	1
39	27	21.8	1
40	20	23.4	2
41	32	25.0	1
42	77	32.0	1
43	28	32.8	1
44	22	35.0	4
45	56	41.6	6
46	10	40.8	1
47	23	33.6	1
48	33	47.2	2
49	77	51.6	4
50	55	41.6	5
51	44	34.4	1
52	31	34.4	1

Contd.....

TABLE 3.9 (PART II) (CONTD.)

ROUTE NO.	NO. OF BUSES PER DAY	ROUND TRIP TIME (MIN.)	NO. OF BUSES PER DAY
54	19	37.6	1
55	20	34.1	1
56	54	36.8	2
57	28	40.8	2
58	87	48.3	4
59	40	53.5	3
60	43	60.0	3
61	109	44.9	5
62	99	65.0	6
63	224	60.8	13
64	53	43.2	3
65	51	41.5	2
66	40	56.0	3
67	20	55.2	2
68	71	66.4	5
69	70	55.0	4
70	29	52.0	2
71	152	68.8	10
72	87	65.4	7
73	120	56.8	7
74	64	56.8	5
75	60	51.6	4
76	48	60.0	3
77	81	63.8	7
78	58	60.0	4
79	24	59.2	2
80	310	52.8	16
81	340	43.2	14
82	50	82.2	4
83	83	89.5	7
84	75	85.0	6
85	22	64.4	2
86	111	113.4	12
87	93	117.0	15
88	29	115.0	4
89	41	36.8	2
90	54	36.8	2
91	45	127.0	6
92	38	143.9	6
93	28	89.7	3
94	42	95.8	4
95	38	96.3	4
96	53	77.4	4
97	32	53.5	2
98	41	67.2	3
99	33	62.0	2
100	104	98.2	10
101	67	104.1	7
102	33	96.2	3
103	17	82.6	13
104	68	98.2	6
105	30	68.4	2
106	72	90.6	7

contd....

TABLE 3.2 (TAPE II) (CONTD.)

NO. OF BUSES PER DAY	NO. OF TRIPS PER DAY	ROUND TRIP TIME (HRS.)	NO. OF BUSES PER DAY
54	77	4	5
87	117	4	10
33	104	2	4
27	97	8	3
22	94	4	3
28	120	4	6
25	84	4	2
27	81	4	4
21	80	4	2
21	91	4	2
22	87	8	3
21	105	8	2
22	68	0	3
27	82	2	3
34	77	4	3
73	60	8	5
51	61	6	3
71	76	2	3
19	61	2	5
88	105	8	2
101	62	4	6
54	107	0	6
55	85	4	5
107	58	4	6
44	125	4	6
25	65	0	2
50	111	8	6
80	65	0	5
37	150	6	6
22	87	0	2
21	42	8	1
165	112	2	1
25	123	8	3
29	136	6	4
94	133	4	12
32	82	2	3
24	79	8	2
35	129	4	1
38	56	0	2
33	91	4	6
62	61	6	2
14	116	2	2
33	82	2	3
120	115	8	1
99	123	0	3
85	77	8	7
54	93	8	5
34	115	0	4
95	129	0	12
30	78	2	3
43	67	2	4
27	66	8	3
52	65	2	2
57	65	0	4

consisting of these 426 links (213 links in each direction) and 134 nodes is used to generate the feasible routes that satisfy the basic requirements of the route and meet the demand. In all 457 routes are generated. The LP model is used to obtain the optimal set of routes and the simultaneous choice of their frequencies for a given fleet size.

The optimal routes and their frequencies are obtained for seven different zones and for the entire network using 3 different operating fleet sizes (670, 750, 790) for the network. The summary of the outputs for all the zones and the entire network for 3 operating fleet sizes are given in Table 3.10. The results indicate that the number of routes in the optimal solution, the number of transfers saved, the average route length are affected by the size of the operating fleet for the network. Fig. 3.5 shows that as the size of the operating fleet for the network increases, the number of routes in the optimal solution also increases. This happens as increased number of vehicles help in running more routes so as to maximize the number of transfers saved. It is also shown in Fig. 3.6 that the more number of transfers are saved with increased number of routes or increased size of the operating fleet. The simple linear relationships obtained for the

TABLE 3.10 : SUMMARY OF OUTPUTS FOR THE DIFFERENT ZONES
AND NETWORK

Sl. No.	Part of Network	Fleet Size	Number of Optimal Routes	Maximum Frequency	Number of Transfers Saved
1	Central	52	8	340	235777
		69	14	340	288417
		88	23	333	323074
2	West	102	35	120	316841
		114	35	120	316841
		117	35	120	316841
3	North	154	34	111	334631
		166	34	111	334631
		172	34	111	334631
4	South-East	99	35	224	354924
		110	43	223	358692
		114	43	223	358692
5	East	64	16	141	200665
		72	30	123	230307
		74	30	123	230307
6	North - East	114	32	170	339228
		125	32	170	339228
		129	32	170	339228
7	South and South-West	85	26	192	269310
		94	28	192	270043
		96	28	192	270043

FOR NETWORK:

TOTAL FLEET SIZE : 670, 750, 790

TOTAL NO. OF OPTIMAL ROUTES: 160, 191, 207

AVERAGE ROUTE LENGTH (Kms.): 6.625, 6.11, 5.8

TOTAL NO. OF TRANSFERS SAVED

(10³) :

2052, 2138, 2173.

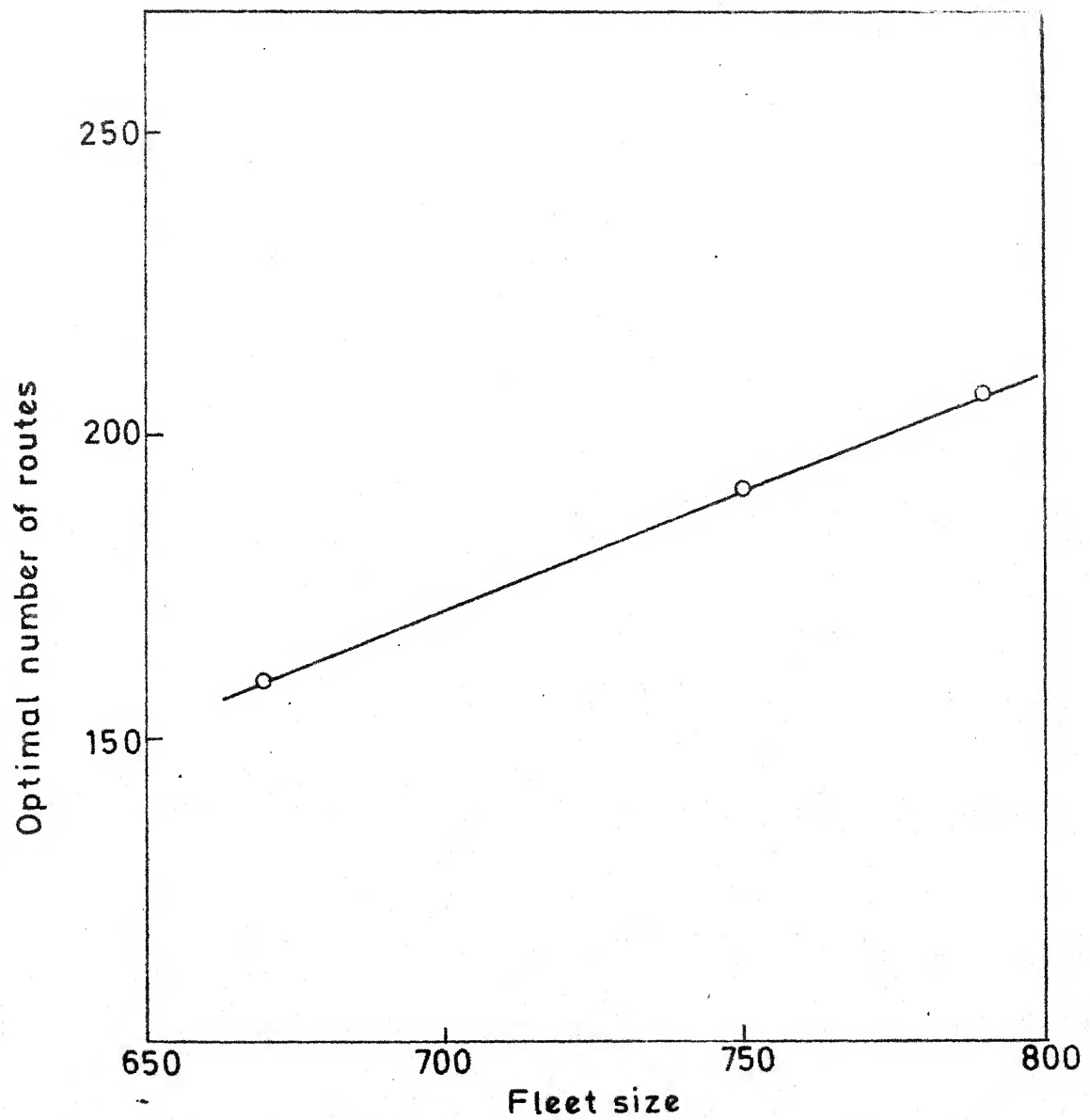


FIG-3-5 RELATIONSHIP BETWEEN OPTIMAL NUMBER OF ROUTES AND FLEET SIZE FOR THE NETWORK.

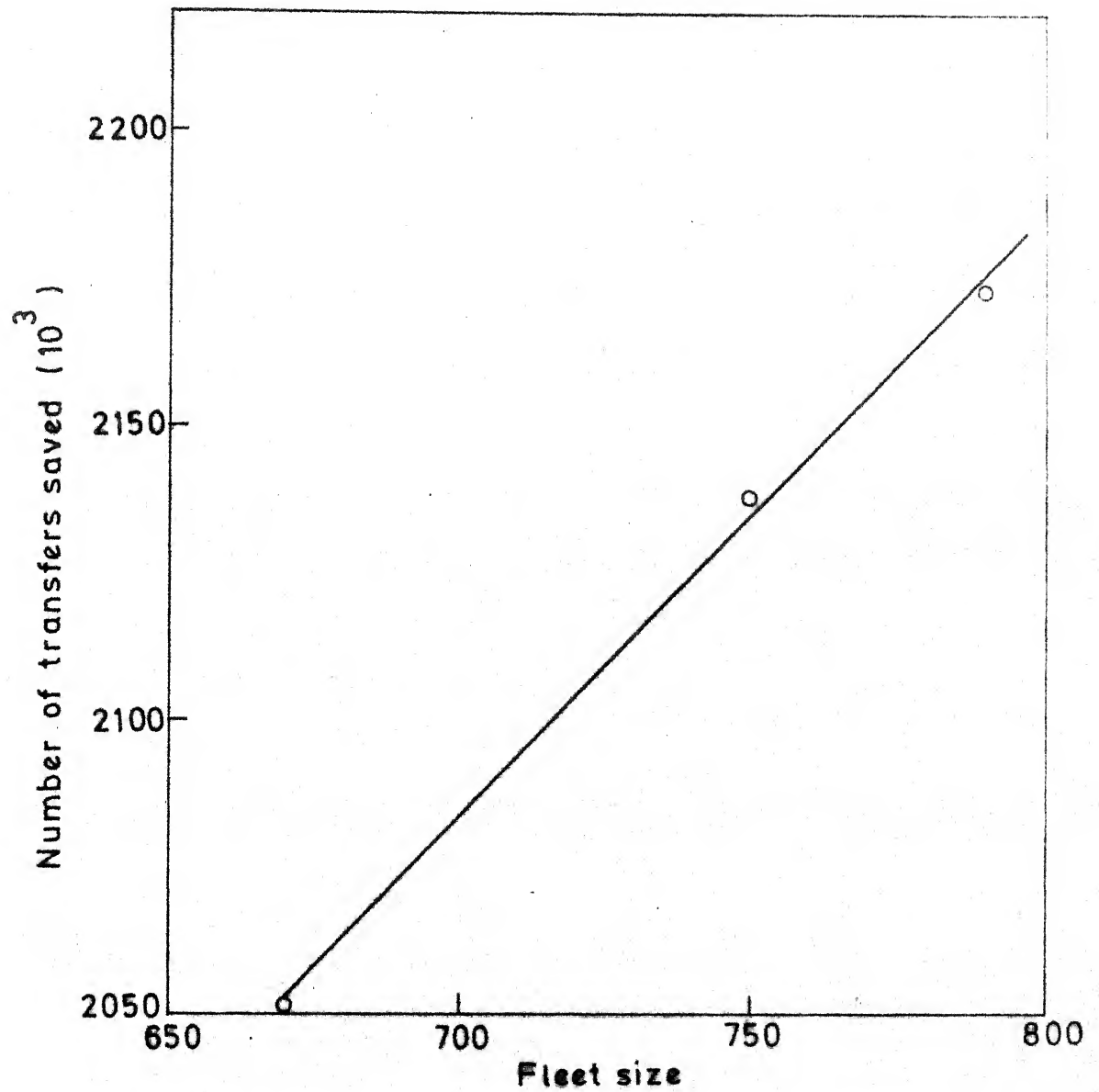


FIG.3-6 RELATIONSHIP BETWEEN NUMBER OF TRANSFERS SAVED AND FLEET SIZE FOR THE NETWORK.

limited range of the operating fleet size as used in this experiment are

$$Y_1 = -102.0893 + 0.39107(X) \quad (3.25)$$

$$(670 \leq X \leq 790)$$

$$Y_2 = 1371179 + 1017.85(X) \quad (3.26)$$

$$(670 \leq X \leq 790)$$

where

- Y_1 = Number of optimal routes
 Y_2 = Number of transfers saved
 X = Operating Fleet size.

By increasing the fleet size, the number of routes in optimal solution increases, then the tendency is to have shorter routes. Fig. 3.7 shows that the average length of the route decreases with fleet size and has the following trend:

$$Y_3 = 11.197 - 0.0068125(X) \quad (3.27)$$

$$(670 \leq X \leq 790)$$

where

- Y_3 = Average length of a route for a network.
 X = Operating fleet size.

The frequency distribution of the route lengths for one size of operating fleet is shown in Fig. 3.8. The length of the routes vary between 2.0 to 20.0 Km. with a mean of 6.625 Kms.

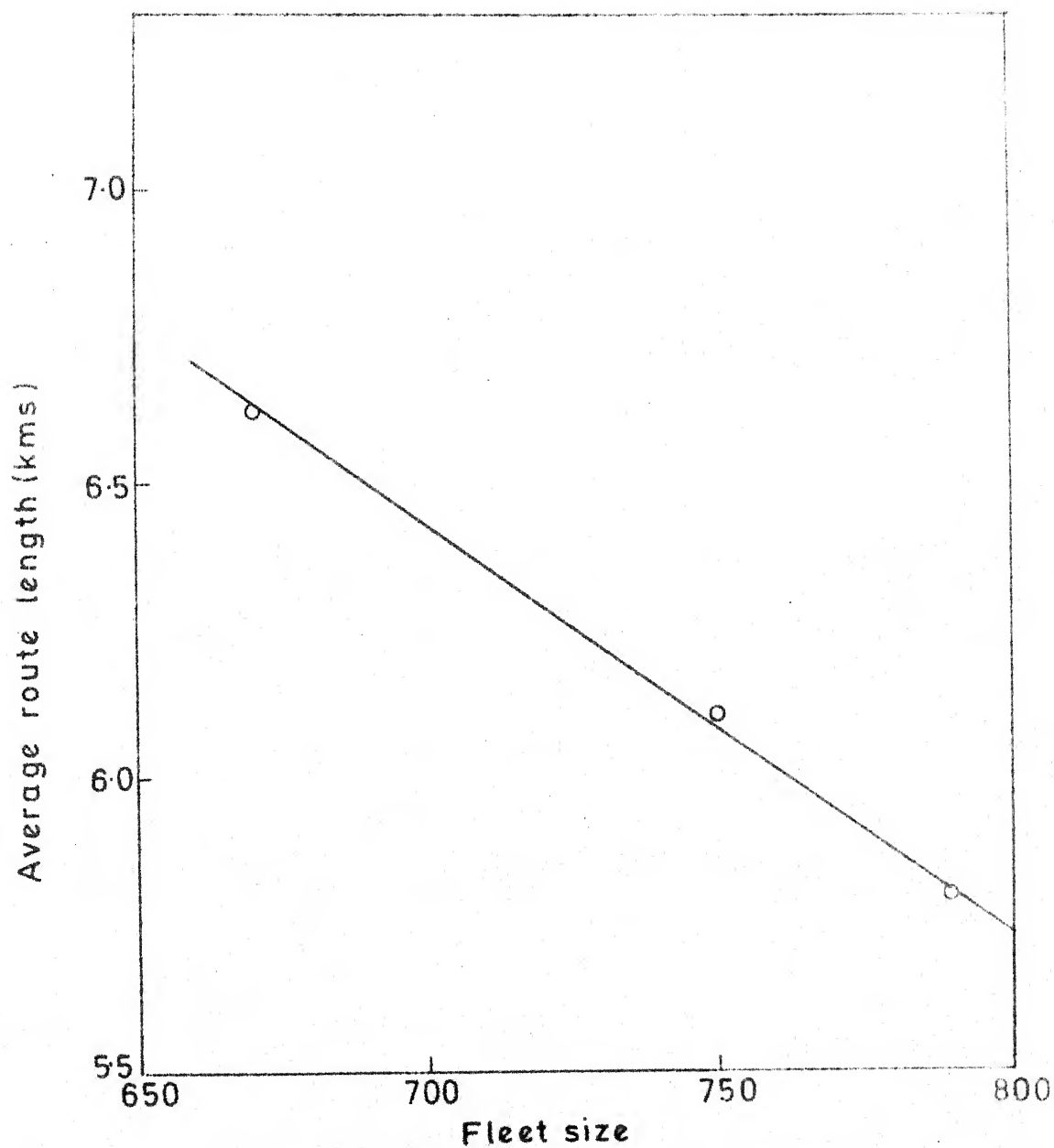


FIG.37 RELATIONSHIP BETWEEN THE AVERAGE ROUTE LENGTH AND FLEET SIZE FOR THE NETWORK.

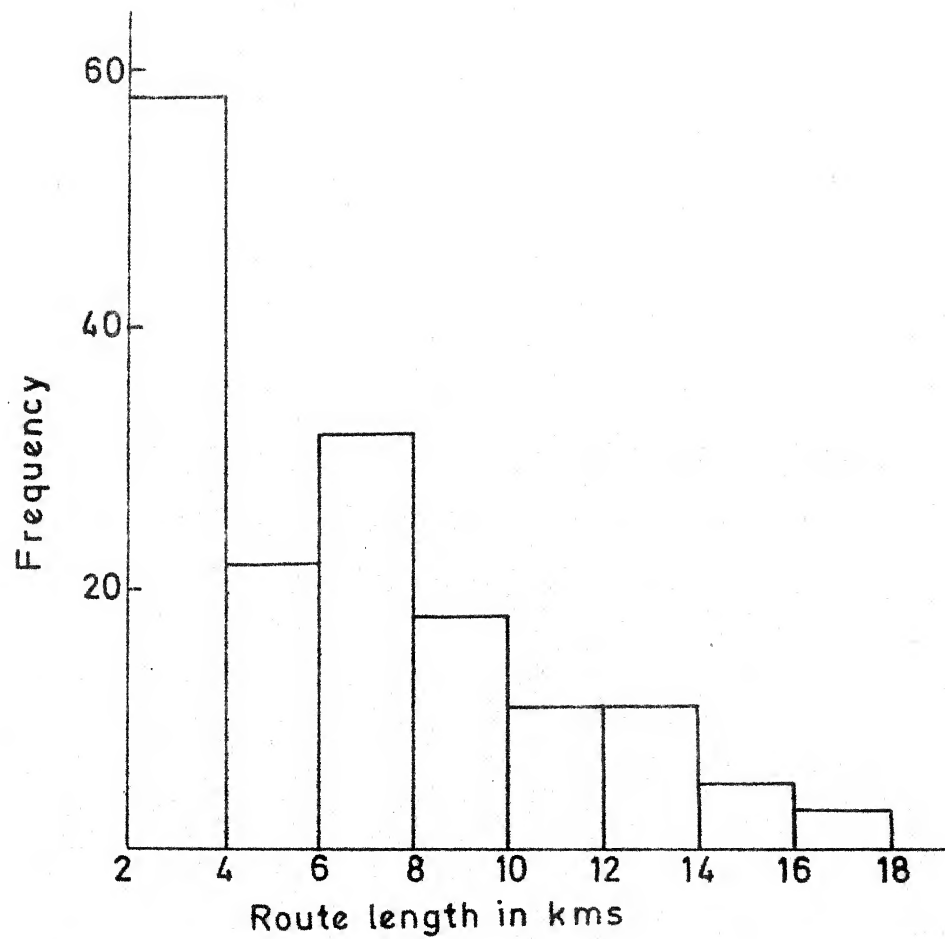


FIG.3.8 FREQUENCY DISTRIBUTION OF ROUTE LENGTHS
FOR OPTIMAL ROUTES (FLEET SIZE=670).

Table 3.11 shows the details of relative loading of the terminals. In the existing network, the two major termini namely Lal-darwaja and Kalupur are already saturated. Lal-darwaja has 77 originating routes and Kalupur has 47 originating routes. The facilities at these two terminals are not adequate and suffer from poor accessibility conditions. But the optimal routes obtained from this model lay relatively less emphasis on the utilisation of Lal-darwaja (node 1) and Kalupur (node 4) termini as it can be seen from the table that 51 routes originate from Lal-darwaja and 30 routes originate from Kalupur termini. In all routes originate from 89 stops.

Table 3.10 indicates that the effect of operating fleet size on the routing system for a zone depends upon its size, traffic demand and the land use pattern. The central zone which is quite small in area compared to other zones has been found to be quite sensitive to changes in fleet size compared to other zones. The optimal routes with their paths obtained for the central zone for 3 different fleet sizes are shown in Figs. 3.9 to 3.11. By changing the fleet size from 52 to 88 the number of routes in the optimal solution increase from 8 to 23. Fig. 3.12 shows the relationships for the optimal number of routes and the number of transfers saved with respect to operating

TABLE 3.11: RELATIONSHIP OF TERMINALS FOR THE OPTIMAL SET OF ROUTES

NO.	NO. OF ROUTES	NO. OF ROUTES	ROUTE NOS.
1	1	51	9 23 24 25 44 45 46 47 48 49 50 57 58 59 60 61
2	1	30	96 97 103 104 105 106 107 110 112 116 117 119 120 122 124
3	1	1	127 128 145 156 157 158
4	1	1	110 123 126 127 128 131 132 134 136 142 143 146 147 149 153 159 160
5	1	1	10 11 12 13 14 15
6	1	1	29 30 31 32 33 34 35
7	1	1	52 76 113 115 121 123 137
8	1	1	11 33 57 66 68 69 70 71 72 73 74 75 80 81 82 83
9	1	1	93 128 133 97 126 130 131 133 138 148 151 154 155
10	1	1	141 142 143 144 145 146 147 148 149 150 151 152 153 154 155
11	1	1	156 157 158 159 160 161 162 163 164 165 166 167 168 169 170
12	1	1	171 172 173 174 175 176 177 178 179 180 181 182 183 184 185
13	1	1	186 187 188 189 190 191 192 193 194 195 196 197 198 199 200
14	1	1	201 202 203 204 205 206 207 208 209 210 211 212 213 214 215
15	1	1	216 217 218 219 220 221 222 223 224 225 226 227 228 229 230
16	1	1	231 232 233 234 235 236 237 238 239 240 241 242 243 244 245
17	1	1	246 247 248 249 250 251 252 253 254 255 256 257 258 259 260
18	1	1	261 262 263 264 265 266 267 268 269 270 271 272 273 274 275
19	1	1	276 277 278 279 280 281 282 283 284 285 286 287 288 289 290
20	1	1	291 292 293 294 295 296 297 298 299 300 301 302 303 304 305
21	1	1	306 307 308 309 310 311 312 313 314 315 316 317 318 319 320
22	1	1	321 322 323 324 325 326 327 328 329 330 331 332 333 334 335
23	1	1	336 337 338 339 340 341 342 343 344 345 346 347 348 349 350
24	1	1	351 352 353 354 355 356 357 358 359 360 361 362 363 364 365
25	1	1	366 367 368 369 370 371 372 373 374 375 376 377 378 379 380
26	1	1	381 382 383 384 385 386 387 388 389 390 391 392 393 394 395
27	1	1	396 397 398 399 400 401 402 403 404 405 406 407 408 409 410
28	1	1	411 412 413 414 415 416 417 418 419 420 421 422 423 424 425
29	1	1	426 427 428 429 430 431 432 433 434 435 436 437 438 439 440
30	1	1	441 442 443 444 445 446 447 448 449 450 451 452 453 454 455
31	1	1	456 457 458 459 460 461 462 463 464 465 466 467 468 469 470
32	1	1	471 472 473 474 475 476 477 478 479 480 481 482 483 484 485
33	1	1	486 487 488 489 490 491 492 493 494 495 496 497 498 499 500
34	1	1	501 502 503 504 505 506 507 508 509 510 511 512 513 514 515
35	1	1	516 517 518 519 520 521 522 523 524 525 526 527 528 529 530
36	1	1	531 532 533 534 535 536 537 538 539 540 541 542 543 544 545
37	1	1	546 547 548 549 550 551 552 553 554 555 556 557 558 559 560
38	1	1	561 562 563 564 565 566 567 568 569 570 571 572 573 574 575
39	1	1	576 577 578 579 580 581 582 583 584 585 586 587 588 589 590
40	1	1	591 592 593 594 595 596 597 598 599 600 601 602 603 604 605
41	1	1	606 607 608 609 610 611 612 613 614 615 616 617 618 619 620
42	1	1	621 622 623 624 625 626 627 628 629 630 631 632 633 634 635
43	1	1	636 637 638 639 640 641 642 643 644 645 646 647 648 649 650
44	1	1	651 652 653 654 655 656 657 658 659 660 661 662 663 664 665
45	1	1	666 667 668 669 670 671 672 673 674 675 676 677 678 679 680</

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TABLE 3.11 (CONT'D.)

ST. NO.	NO. OF ROUTES	ROUTE NOS.	
		4000	5000
26	5	67	58 08 131
27	1	150	
28	3	125	
29	4	117	118 135
30	4	116	111 112
31	3	95	07 101 102
32	2	105	17
33	3	105	47 48
34	2	11	
35	1	95	
36	1	60	
37	3	34	35 109 118 140 144
38	7	32	
39	1	132	
40	1	127	
41	4	118	37 38 63
42	5	91	124 141 143 144
43	2	93	
44	2	139	142
45	2	139	146
46	1	119	
47	2	118	20
48	2	118	14
49	1	54	69 109 111 118 151 152 153 154
50	1	157	
51	1	113	14
52	5	113	21 24 25 55
53	2	39	49
54	3	83	84 102 108 150
55	3	37	55 146
56	5	7	20 37 50
57	2	15	21

Contd.....

100

ST. NO.	CODE	QUANTITY	PRICE	AMOUNT	DATE	NO.
1	100	1	100	100	1	1
2	100	1	100	100	2	2
3	100	1	100	100	3	3
4	100	1	100	100	4	4
5	100	1	100	100	5	5
6	100	1	100	100	6	6
7	100	1	100	100	7	7
8	100	1	100	100	8	8
9	100	1	100	100	9	9
10	100	1	100	100	10	10
11	100	1	100	100	11	11
12	100	1	100	100	12	12
13	100	1	100	100	13	13
14	100	1	100	100	14	14
15	100	1	100	100	15	15
16	100	1	100	100	16	16
17	100	1	100	100	17	17
18	100	1	100	100	18	18
19	100	1	100	100	19	19
20	100	1	100	100	20	20
21	100	1	100	100	21	21
22	100	1	100	100	22	22
23	100	1	100	100	23	23
24	100	1	100	100	24	24
25	100	1	100	100	25	25
26	100	1	100	100	26	26
27	100	1	100	100	27	27
28	100	1	100	100	28	28
29	100	1	100	100	29	29
30	100	1	100	100	30	30
31	100	1	100	100	31	31
32	100	1	100	100	32	32
33	100	1	100	100	33	33
34	100	1	100	100	34	34
35	100	1	100	100	35	35
36	100	1	100	100	36	36
37	100	1	100	100	37	37
38	100	1	100	100	38	38
39	100	1	100	100	39	39
40	100	1	100	100	40	40
41	100	1	100	100	41	41
42	100	1	100	100	42	42
43	100	1	100	100	43	43
44	100	1	100	100	44	44
45	100	1	100	100	45	45
46	100	1	100	100	46	46
47	100	1	100	100	47	47
48	100	1	100	100	48	48
49	100	1	100	100	49	49
50	100	1	100	100	50	50
51	100	1	100	100	51	51
52	100	1	100	100	52	52
53	100	1	100	100	53	53
54	100	1	100	100	54	54
55	100	1	100	100	55	55
56	100	1	100	100	56	56
57	100	1	100	100	57	57
58	100	1	100	100	58	58
59	100	1	100	100	59	59
60	100	1	100	100	60	60
61	100	1	100	100	61	61
62	100	1	100	100	62	62
63	100	1	100	100	63	63
64	100	1	100	100	64	64
65	100	1	100	100	65	65
66	100	1	100	100	66	66
67	100	1	100	100	67	67
68	100	1	100	100	68	68
69	100	1	100	100	69	69
70	100	1	100	100	70	70
71	100	1	100	100	71	71
72	100	1	100	100	72	72
73	100</					

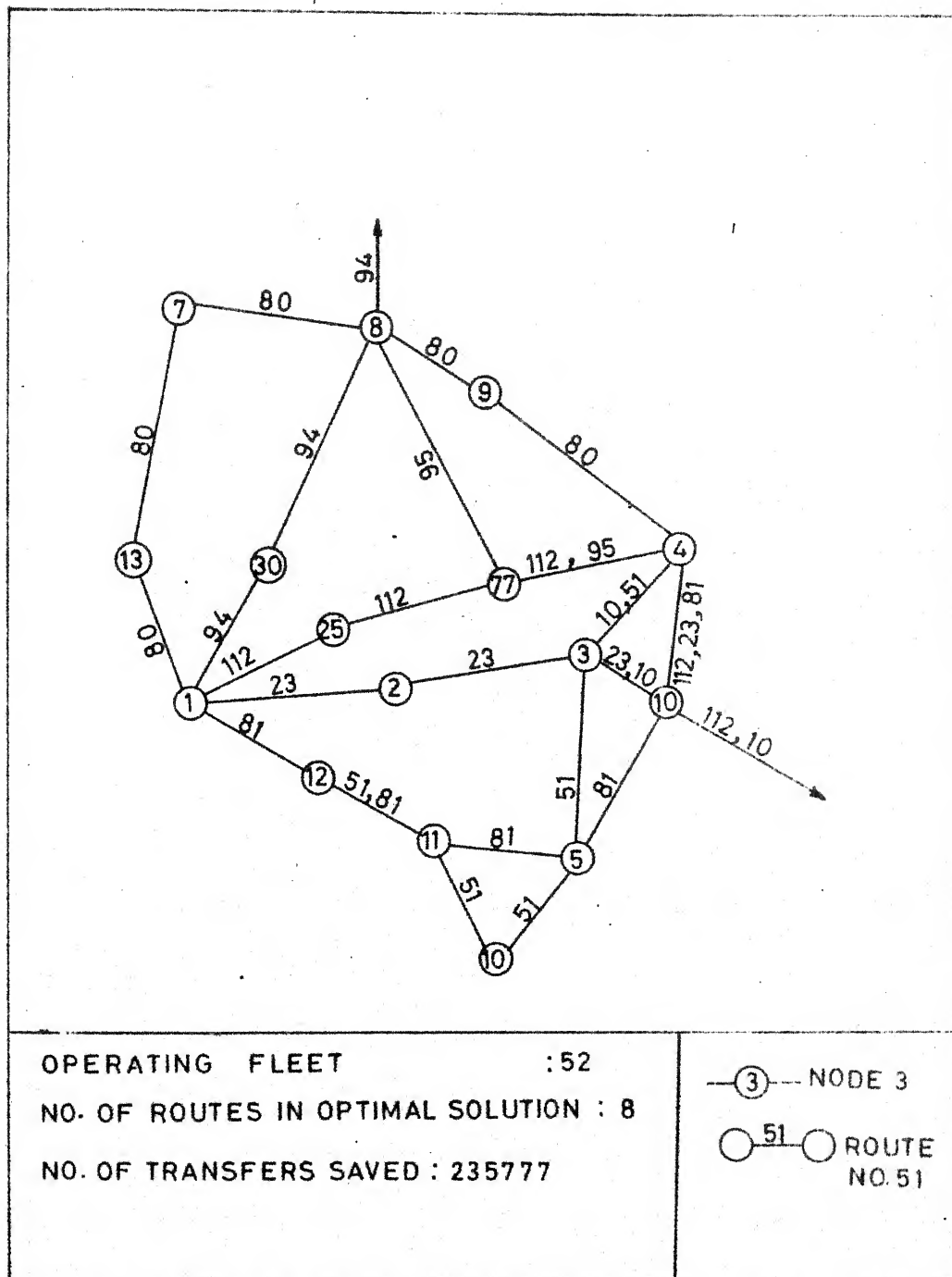


FIG. 3-9 ROUTE NETWORK FOR CENTRAL ZONE
 (OPERATING FLEET=52).

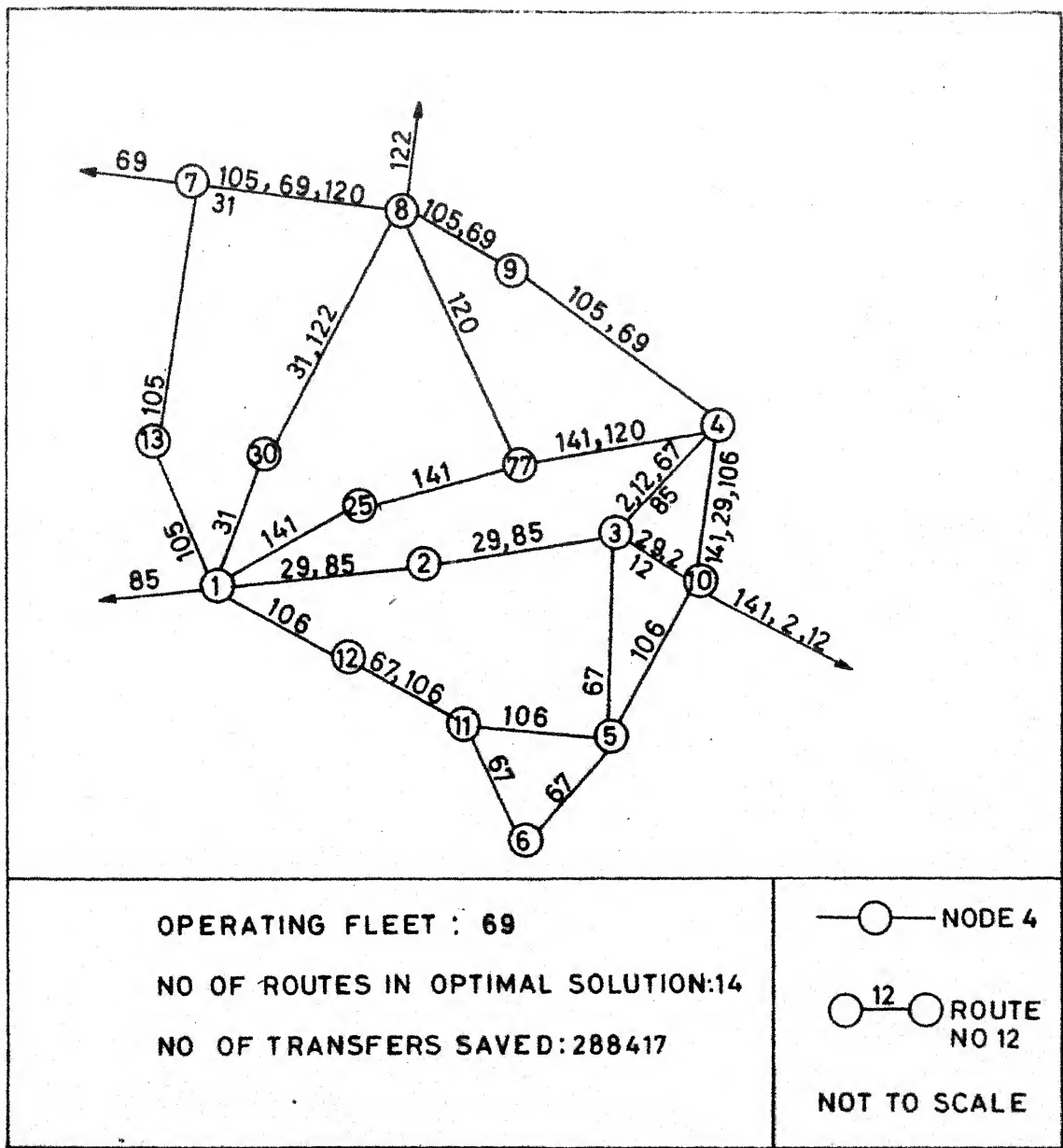


FIG.310 ROUTE NETWORK FOR CENTRAL ZONE(OPERATING FLEET=69).

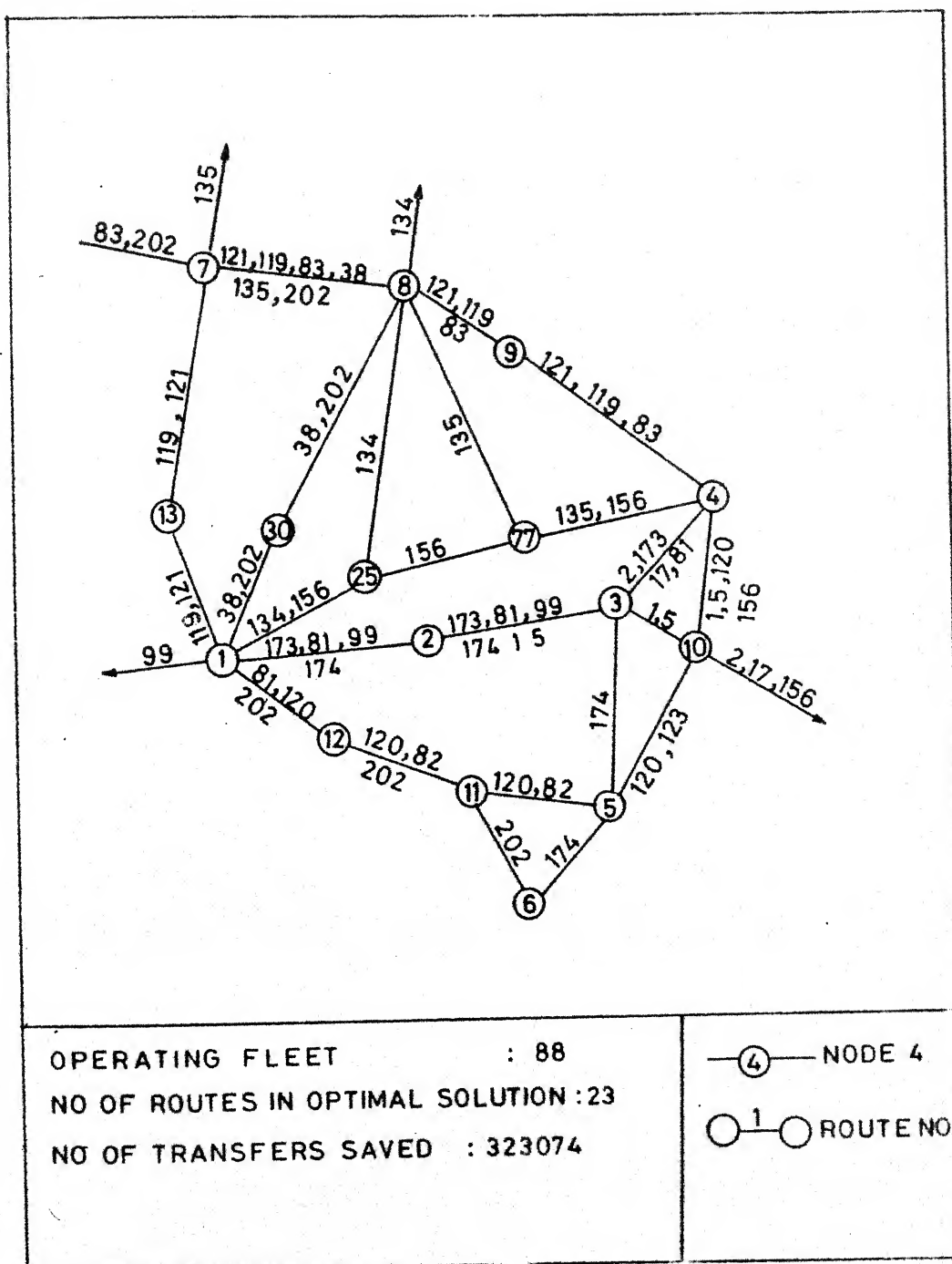


FIG-3-11 ROUTE NETWORK FOR CENTRAL ZONE
 (OPERATING FLEET=88).

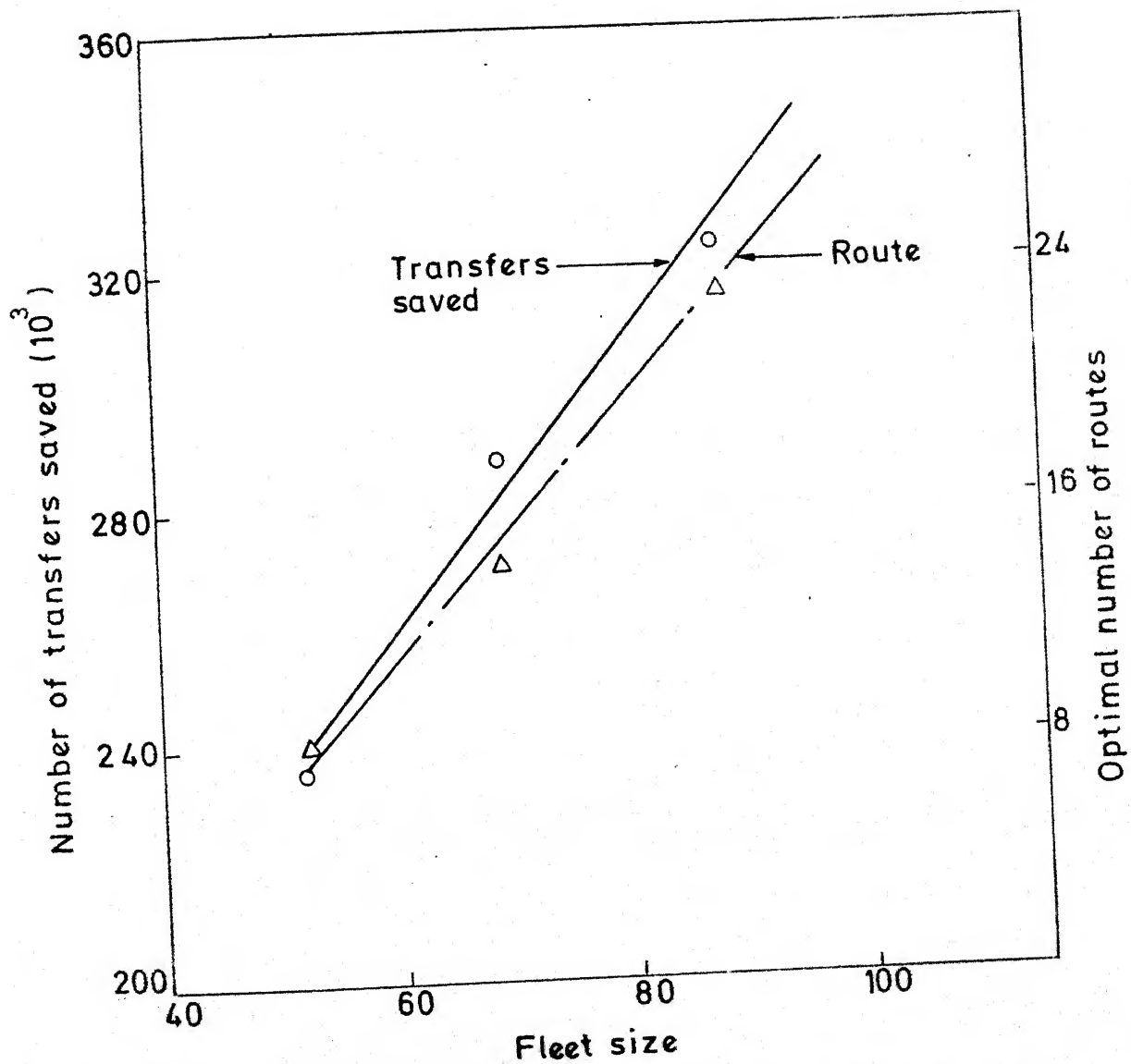


FIG.3.12 RELATIONSHIPS BETWEEN NUMBER OF TRANSFERS SAVED, OPTIMAL NUMBER OF ROUTES AND FLEET SIZE (Central zone).

fleet size of the central zone. Mathematically, the relations can be expressed as:

$$Y_4 = -14.105 + 0.41778(X) \quad (3.28)$$

$$(52 \leq X \leq 88)$$

$$Y_5 = 114304.2 + 2413.183(X) \quad (3.29)$$

$$(52 \leq X \leq 88)$$

where

Y_4 = The optimal number of routes

Y_5 = The number of transfers saved

X = Operating fleet size for the central zone.

The coefficients for the above equations differ from those of the Eqns. 3.25 , 3.26 for the entire network. These coefficients can similarly be obtained for other zones.

The maximum frequency of a route in a zone depends upon the travel demand. Table 3.10 indicates that the maximum frequency is insensitive to the range of the operating fleet sizes considered in this experiment.

4 SUMMARY, CONCLUSIONS AND SUGGESTIONS

4.1 Summary

A few major limitations of the past research in the area of routing and scheduling of the bus transit system are : (i) the generation of routes and scheduling of vehicle in the network is done sequentially, (ii) evaluation of alternative paths of a route is carried out independent of the already accepted routes for the network.

In this study, an attempt has been made to develop a method such that the selection of the routes and the assignment of frequencies is done simultaneously for the bus transit system. The method has been developed in four stages: (i) to generate a trip distribution matrix, (ii) to concentrate the flow of passengers on the road network such that the sum of passenger-riding-time-cost and operation cost is minimized, (iii) to generate a large set of all possible routes that satisfy the various constraints, (iv) to select routes and their frequencies so that number of transfers saved on the network is maximized. Heuristics have been used for the concentration of the flow and generation of the routes while Linear Programming (LP) has been used to select routes and their frequencies.

A method has been suggested to estimate trip distribution matrix by using generally available traffic data of the existing routes for the city bus network.

The flow of passengers on the various links of the network is concentrated such that the sum of passenger-riding-time-cost and operation cost of the vehicles is minimized. An heuristic algorithm has been developed for concentrating the flow. The relationship between the number of bus trips and the flow of passengers on a link has also been derived. The starting network consists of all the links where vehicles could possibly travel. Passenger flows have been systematically concentrated by eliminating the links, in stages such that the total cost is minimized.

For a given desired travel matrix, a large set of all possible routes between different O-D pairs is generated using an heuristic procedure. The generated routes satisfy the practical constraints of length and the deviation from the shortest path.

The total number of transfers saved on a route is determined based on the size of the turning movements along the route and the estimated number of bus trips on the links. For a given operating fleet size, the

simultaneous selection of routes and their frequencies is done by Linear Programming such that the total number of transfers saved on the network is maximized.

Ahmedabad city has been chosen for the case study for structuring of the bus transit network. The optimal set of routes and their frequencies have been estimated for three operating fleet sizes.

4.2 Conclusions

The proposed method is a valuable tool for simultaneous selection of optimal routes and their frequencies for a bus transit network. It can be used by the planner in:

- (i) structuring of routes in a rational and systematic way for the given spatial distribution of travel demand;
- (ii) finding the number of buses and frequencies on each route and operating fleet size for the system.

Based on the application of the model for the city of Ahmedabad, the following conclusions can also be drawn:

- (a) The suggested procedure for the estimation of O-D matrix uses the generally available traffic data of the existing routes in a city bus network. In

cities where trip distribution matrix is not available this method is quite valuable.

- (b) The number of bus trips (Y) on a link for a day varies with the passenger flow (X) on the link. The relationship has been established for the city of Ahmedabad and is of the form $Y = aX^b$.
- (c) For a given spatial distribution of travel demand, the optimal total cost (passenger-riding-time-cost + operation cost) can be obtained from the algorithm that concentrates the flow on the links.
- (d) The method first distributes the passengers on the links in the network and then generates routes that follow the passengers. This method is computationally quite efficient, compared to other methods that repeatedly distribute the passengers on trial networks.
- (e) Route generating procedure developed in this study is a systematic and rational algorithm to generate a large set of all possible routes that satisfy the various requirements.
- (f) Selection of optimal set of routes and their frequencies is made through an Linear Programming formulation which maximizes the number of transfers saved on the network. This method is more realistic

as the interaction of various routes is taken into consideration.

- (g) The application of the model to the city of Ahmedabad indicates that the model can be successfully applied for a large size transit networks and the results are quite encouraging.
- (h) The results indicate that the number of routes in the optimal solution, number of transfers saved, increase linearly with increase in operating fleet size. However the average length of the route decreases with the increase in operating fleet size.

4.3 Suggestions for Future Study

Any future work in this direction may include the consideration of the following aspects of the problem:

1. Structuring of routes and the assignment of frequencies is done for a given desired trip matrix. Further refinement of the suggested model may take care of the stochastic variations in the travel demand.
2. The frequencies assigned are for the day. The variations of headways during the day need to be investigated.

3. Operater cost and passenger-riding-time-cost have been considered in terms of time by estimating their weights. The analysis can be made more realistic by considering the actual costs.

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APPENDIX I

STOPS IN AHMEDABAD CITY BUS NETWORK

Code No.	Name of the stop	No. of routes touching the stop
1	2	3
1	Lal Darwaja	98
2	Fuwara	6
3	Khadia Char Rasta	10
4	Kalupur	70
5	Raipur Darwaja	47
6	S.T. Bus Station	24
7	Sharpur Chakla	27
8	Delhi Darwaja	58
9	Dariapur Tower	10
10	Sarangpur	55
11	Astodia Chakla	36
12	Khamasa	43
13	Khanpur	8
14	Municipal Staff Quarters (Dudheshwar)	6
15	Dudheshwar	6
16	Dariakhan Ghummat	2
17	Maninagar	23
18	Jawahar Chowk (Maninagar)	10

Contd.....

Appendix I contd...

1	2	3
19	Shah Alam Tol Naka	14
20	Patel Mills	13
21	Bapunagar Terminus	6
22	Bapunagar Char Rasta (Vina Hospital)	9
23	Bombay Housing Colony	8
24	Shardaben Hospital	18
25	Patthar Kuwa	13
26	Income Tax Office	50
27	Sardar Stadium	10
28	Lal Bunglow (Lal College)	8
29	Panchavatti	18
30	Mirzapur Gardens (Jansatta)	23
31	Nutan Society	6
32	Paldi	30
33	Jamalpur Char Rasta	15
34	Pushpa Kunj	16
35	Uttamnagar	4
36	Isanpur	4
38	Daxini Society	4
39	Krishna Baug	15
40	L.G. Corner	10

Contd....

Appendix I contd..

1	2	3
41	Major Dairy	17
42	Idgah Chowky	16
43	Haripura	10
44	Civil Corner	3
45	Civil Hospital	18
46	Dafnala	9
47	Sadar Bazar Camp	6
48	Sardarnagar	4
49	Laxminarayan Society	5
50	Ambica Mills	11
51	New Cottan Mills	5
52	Gontipur Darwaja	11
53	Rakhial Char Rasta	18
54	Chamunda	18
55	Chamanpura Choktha	10
56	Asarwa Chakla	12
57	Kamdar Maidan	24
58	Girdharnagar	13
59	Circuit House	10
60	Khokhra Mehmabad	12
61	Amraiwadi	5
62	M.L.A. Quats.	16
63	Meghaninagar	10

Contd.....

Appendix I contd...

1	2	3
64	Chandola Lake	6
65	S.T. Workshop	6
66	Ganghidham Station	47
67	Fatehnagar	12
68	Vasna	11
69	Juhapura	5
70	P.T. College	5
71	Narayannagar	4
72	Ayojannagar	3
73	Sharda Society	5
74	Chamanpura Hous. College	4
75	V.S. Hospital	16
76	Naranghat Rly. X	21
77	Dhana Suthar's Pol	12
78	Rajnagar Society	5
79	Guj. Friends Soce.	8
80	Raikhad Char Rasta	2
81	Sharda Nandir	3
82	Gujarat University	22
83	St Xavier School	5
84	Naranpura Char Rasta	10

Contd.....

Appendix I contd...

1	2	3
85	Ankur Society	6
86	Gujarat College	19
87	Law College	16
88	Politechnique	11
89	Nilima Park	7
90	Commerce College	18
91	Govnt. Quats. (Ambawadi)	9
92	Jodhpur Gam	4
93	Navrangpura	17
94	Nataraj Cinema	14
95	Sanyas Ashram	48
96	Industrial Corner	3
97	Lal Mills	11
98	Gandhi Chotra	3
99	Usmanpura	36
100	Shri Niketan Society	3
101	Naranpura	5
102	Sardar Patel Colony	6
103	St. Joseph H. School	3
104	Memnagar Garnala	5
105	Vijaynagar	5

Contd....

Appendix I contd...

1	2	3
106	Zoo	15
107	Bapunagar Char Rasta	7
108	L.B.Shashtri Stadium	5
109	Govnt.Colony(Lal Mills)	12
110	Vadaj	28
111	Nava Vadaj	4
112	Vora Roza	9
113	Bombay Housing(Vora Roza)	2
114	Advance Mills	19
117	Saijpur	9
118	Krishnanagar	3
119	Thakkar Bapanagar	2
120	Sabarmati Tolnaka	26
121	Broad Gag. Over Br.	20
122	Jawahar Chowk	10
123	Ramnagar	9
124	O.N.G.C.	6
125	Omkareshvar Mahadev	5
130	Ajit Mills	8
132	Kabir Chowk	10
133	Nagavel Hanuman	6
Contd.....		

Appendix I contd...

1	2	3
134	Ramrajayanagar	3
135	Rabari Colony	3
136	Hatkeshvar Mahadev	6
137	C.N. Vidhalaya	13
138	Ashok Mills	12
139	Ranipur	5
140	Sewage Farm	2
141	Jivraj Park	2
142	Metre Gauge Garnala	1

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APPENDIX II (contd.)

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APPENDIX II (contd.)

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APPENDIX II (contd.)

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APPENDIX II (contd.)

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APPENDIX II (contd.)

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APPENDIX II (contd.)

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132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
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APPENDIX III (contd.)

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APPENDIX III (contd.)

ROUTE NO.	ROUTE LENGTH	TRANSFER	MODES	TOUCHED BY A	ROUTE
77	66	66	75	96	
13	13	66	94	94	
25	13	66	95	95	
11	11	11	7		
41	41	41			
34	34	34			
109	109	109			
112	112	112			
112	112	112			
10	10	10			
24	24	24			
108	108	108			

contd.....

APPENDIX III (contd.)

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APPENDIX III (contd.)

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APPENDIX III (contd.)

ROUTE NO.	ROUTE LENGTH	TRANSFER SAVED	NODES	TOUCHED	BY A ROUTE
1	5	318	75	96	99
2	5	967	21		
3	5	1248	34		
4	5	144	56	99	
5	5	164	26		
6	5	130	108	17	
7	5	130	139		
8	5	130	17		
9	5	130	41	34	17
10	5	130	41	40	
11	5	130	47	82	
12	5	130	60		
13	5	130	198	18	
14	5	130	144	34	
15	5	130	144	45	
16	5	130	144	68	
17	5	130	144	82	
18	5	130	144	110	
19	5	130	144	41	17
20	5	130	144	17	
21	5	130	144	6	41
22	5	130	144	17	40
23	5	130	144	32	17
24	5	130	144	32	
25	5	130	144	75	86
26	5	130	144	110	
27	5	130	144	110	
28	5	130	144	110	
29	5	130	144	110	
30	5	130	144	110	
31	5	130	144	110	
32	5	130	144	110	
33	5	130	144	110	
34	5	130	144	110	
35	5	130	144	110	
36	5	130	144	110	
37	5	130	144	110	
38	5	130	144	110	
39	5	130	144	110	
40	5	130	144	110	
41	5	130	144	110	
42	5	130	144	110	
43	5	130	144	110	
44	5	130	144	110	
45	5	130	144	110	
46	5	130	144	110	
47	5	130	144	110	
48	5	130	144	110	
49	5	130	144	110	
50	5	130	144	110	
51	5	130	144	110	
52	5	130	144	110	
53	5	130	144	110	
54	5	130	144	110	
55	5	130	144	110	
56	5	130	144	110	
57	5	130	144	110	
58	5	130	144	110	
59	5	130	144	110	
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61	5	130	144	110	
62	5	130	144	110	
63	5	130	144	110	
64	5	130	144	110	
65	5	130	144	110	
66	5	130	144	110	
67	5	130	144	110	
68	5	130	144	110	
69	5	130	144	110	
70	5	130	144	110	
71	5	130	144	110	
72	5	130	144	110	
73	5	130	144	110	
74	5	130	144	110	
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93	5	130	144	110	
94	5	130	144	110	
95	5	130	144	110	
96	5	130	144	110	
97	5	130	144	110	
98	5	130	144	110	
99	5	130	144	110	
100	5	130	144	110	

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ROUTE	ROUTE LENGTH	TRANSFER SAVED	NODES	TOUCHED BY A	ROUTE
1	100	100	1	32	32
2	100	100	1	32	32
3	100	100	1	32	32
4	100	100	1	32	32
5	100	100	1	32	32
6	100	100	1	32	32
7	100	100	1	32	32
8	100	100	1	32	32
9	100	100	1	32	32
10	100	100	1	32	32
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12	100	100	1	32	32
13	100	100	1	32	32
14	100	100	1	32	32
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18	100	100	1	32	32
19	100	100	1	32	32
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22	100	100	1	32	32
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27	100	100	1	32	32
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42	100	100	1	32	32
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63	100	100	1	32	32
64	100	100	1	32	32
65	100	100	1	32	32
66	100	100	1	32	32
67	100	100	1	32	32
68	100	100	1	32	32
69	100	100	1	32	32
70	100	100	1	32	32
71	100	100	1	32	32
72	100	100	1	32	32

APPENDIX III (contd.)

ROUTE NO.	ROUTE LENGTH	TRANSFER SAVED	NODES	TOUCHED	BY	A	ROUTE
352	95	352	7	110	120	121	123 124
353	95	353	7	110	120	121	124
354	95	354	114	125	123	124	
355	95	355	76	121	122		
356	95	356	76	120			
357	95	357	110	99 102	27	90	82 79 98 137
358	95	358	94	26	99	110	120 121 122
359	95	359	99	26	7	114	121 122 124
360	95	360	99	26	7	114	121 122 124
361	95	361	99	26	7	114	121 122 124
362	95	362	99	26	7	114	121 122 124
363	95	363	99	26	7	114	121 122 124
364	95	364	99	26	7	114	121 122 124
365	95	365	99	26	7	114	121 122 124
366	95	366	99	26	7	114	121 122 124
367	95	367	99	26	7	114	121 122 124
368	95	368	99	26	7	114	121 122 124
369	95	369	99	26	7	114	121 122 124
370	95	370	99	26	7	114	121 122 124
371	95	371	99	26	7	114	121 122 124
372	95	372	99	26	7	114	121 122 124
373	95	373	99	26	7	114	121 122 124
374	95	374	99	26	7	114	121 122 124
375	95	375	99	26	7	114	121 122 124
376	95	376	99	26	7	114	121 122 124
377	95	377	99	26	7	114	121 122 124
378	95	378	99	26	7	114	121 122 124
379	95	379	99	26	7	114	121 122 124
380	95	380	99	26	7	114	121 122 124
381	95	381	99	26	7	114	121 122 124
382	95	382	99	26	7	114	121 122 124
383	95	383	99	26	7	114	121 122 124
384	95	384	99	26	7	114	121 122 124
385	95	385	99	26	7	114	121 122 124
386	95	386	99	26	7	114	121 122 124
387	95	387	99	26	7	114	121 122 124
388	95	388	99	26	7	114	121 122 124
389	95	389	99	26	7	114	121 122 124
390	95	390	99	26	7	114	121 122 124
391	95	391	99	26	7	114	121 122 124
392	95	392	99	26	7	114	121 122 124
393	95	393	99	26	7	114	121 122 124
394	95	394	99	26	7	114	121 122 124
395	95	395	99	26	7	114	121 122 124
396	95	396	99	26	7	114	121 122 124
397	95	397	99	26	7	114	121 122 124
398	95	398	99	26	7	114	121 122 124
399	95	399	99	26	7	114	121 122 124
400	95	400	99	26	7	114	121 122 124
401	95	401	99	26	7	114	121 122 124
402	95	402	99	26	7	114	121 122 124
403	95	403	99	26	7	114	121 122 124
404	95	404	99	26	7	114	121 122 124
405	95	405	99	26	7	114	121 122 124
406	95	406	99	26	7	114	121 122 124
407	95	407	99	26	7	114	121 122 124
408	95	408	99	26	7	114	121 122 124
409	95	409	99	26	7	114	121 122 124
410	95	410	99	26	7	114	121 122 124
411	95	411	99	26	7	114	121 122 124
412	95	412	99	26	7	114	121 122 124
413	95	413	99	26	7	114	121 122 124
414	95	414	99	26	7	114	121 122 124
415	95	415	99	26	7	114	121 122 124
416	95	416	99	26	7	114	121 122 124
417	95	417	99	26	7	114	121 122 124
418	95	418	99	26	7	114	121 122 124
419	95	419	99	26	7	114	121 122 124
420	95	420	99	26	7	114	121 122 124
421	95	421	99	26	7	114	121 122 124
422	95	422	99	26	7	114	121 122 124
423	95	423	99	26	7	114	121 122 124
424	95	424	99	26	7	114	121 122 124
425	95	425	99	26	7	114	121 122 124
426	95	426	99	26	7	114	121 122 124
427	95	427	99	26	7	114	121 122 124
428	95	428	99	26	7	114	121 122 124
429	95	429	99	26	7	114	121 122 124
430	95	430	99	26	7	114	121 122 124
431	95	431	99	26	7	114	121 122 124
432	95	432	99	26	7	114	121 122 124
433	95	433	99	26	7	114	121 122 124
434	95	434	99	26	7	114	121 122 124
435	95	435	99	26	7	114	121 122 124
436	95	436	99	26	7	114	121 122 124
437	95	437	99	26	7	114	121 122 124
438	95	438	99	26	7	114	121 122 124
439	95	439	99	26	7	114	121 122 124
440	95	440	99	26	7	114	121 122 124
441	95	441	99	26	7	114	121 122 124
442	95	442	99	26	7	114	121 122 124
443	95	443	99	26	7	114	121 122 124
444	95	444	99	26	7	114	121 122 124
445	95	445	99	26	7	114	121 122 124
446	95	446	99	26	7	114	121 122 124
447	95	447	99	26	7	114	121 122 124
448	95	448	99	26	7	114	121 122 124
449	95	449	99	26	7	114	121 122 124
450	95	450	99	26	7	114	121 122 124
451	95	451	99	26	7	114	121 122 124
452	95	452	99	26	7	114	121 122 124
453	95	453	99	26	7	114	121 122 124
454	95	454	99	26	7	114	121 122 124
455	95	455	99	26	7	114	121 122 124
456	95	456	99	26	7	114	121 122 124
457	95	457	99	26	7	114	121 122 124
458	95	458	99	26	7	114	121 122 124
459	95	459	99	26	7	114	121 122 124
460	95	460	99	26	7	114	121 122 124
461	95	461	99	26	7	114	121 122 124
462	95	462	99	26	7	114	121 122 124
463	95	463	99	26	7	114	121 122 124
464	95	464	99	26	7	114	121 122 124
465	95	465	99	26	7	114	121 122 124
466	95	466	99	26	7	114	121 122 124
467	95	467	99	26	7	114	121 122 124
468	95	468	99	26	7	114	121 122 124
469	95	469	99	26	7	114	121 122 124
470	95	470	99	26	7	114	121 122 124
471	95	471	99	26	7	114	121 122 124
472	95	472	99	26	7	114	121 122 124
473	95	473	99	26	7	114	121 122 124
474	95	474	99	26	7	114	121 122 124
475	95	475	99	26	7	114	121 122 124
476	95	476	99	26	7	114	121 122 124
477	95	477	99	26	7	114	121 122 124
478	95	478	99	26	7	114	121 122 124
479	95	479	99	26	7	114	121 122 124
480	95	480	99	26	7	114	121 122 124
481	95	481	99	26	7	114	121 122 124
482	95	482	99	26	7	114	121 122 124
483	95	483	99	26	7	114	121 122 124
484	95	484	99	26	7	114	121 122 124
485	95	485	99	26	7	114	121 122 124
486	95	486	99	26	7	114	121 122 124
487	95	487	99	26	7	114	121 122 124
488	95	488	99	26	7	114	121 122 124
489	95	489	99	26	7	114	121 122 124
490	95	490	99	26	7	114	121 122 124
491	95	491	99	26	7	114	121 122 124
492	95	492	99	26	7	114	121 122 124
493	95	493	99	26	7	114	121 122 124
494	95	494	99	26	7	114	121 122 124
495	95	495	99	26	7	114	121 122 124
496	95	496	99	26	7	114	121 122 124
497	95	497	99	26	7	114	121 122 124
498	95	498	99	26	7	114	121 122 124
499	95	499	99	26	7	114	121 122 124
500	95	500	99	26	7	114	121 122 124
501	95	501	99	26	7	114	121 122 124
502	95	502	99	26	7	114	121 122 124
503	95	503	99	26	7	114	121 122 124
504	95	504	99	26	7	114	121 122 124
505	95	505	99	26	7	114	121 122 124
506	95	506	99	26	7	114	121 122 124
507	95	507	99	26	7	114	121 122 124
508	95	508	99	26	7	114	121 122 124
509	95	509	99	26	7	114	121 122 124
510	95	510	99	26	7	114	121 122 124
511	95	511	99	26	7	114	121 122 124
512	95	512	99	26	7	114	121 122 124
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514	95	514	99	26	7	114	121 122 124
515	95	515	99	26	7	114	121 122 124
516	95	516	99	26	7	114	121 122 124
517	95	517	99	26	7	114	121 122 124
518	95	518	99	26	7	114	121 122 124
519	95	519	99	26	7	114	121 122 124
52							

ROUTE NO.	ROUTE LENGTH	TRANSFER SAVED	VOICES	TOUCHED	BY	A	ROUTE
1	13	1	7	13			
2	108	96	108				
3	97	53					
4	26	93	90	82	79	88	
5	102	89	82				
6	130	133	57	52	53		
7	111	135					
8	153	130					
9	134						
10	108						
11	45						
12	62						
13	50	60	136	61	135		
14	136						
15	149						
16	17	49					
17	49						
18	42	56	62	63			
19	42	56	62				
20	35	36					
21	139						
22	139						
23	69						
24	69						
25	72	141					
26	58	69					
27	110	120	121	122			

ROUTE NO.	ROUTE LENGTH	TRANSFER SAVED	NODES	TOUCHED	BY	A	ROUTE
1	100	399	94	110	120	121	122
2	100	399	117	121	122	121	122
3	100	399	124	110	120	121	122
4	100	399	138	10	54	138	117
5	100	399	111	118			
6	100	399	133	103	51	135	
7	100	399	111				
8	100	399	130				
9	100	399	141	50	49		
10	100	399	141	50	51		
11	100	399	141	50	136		
12	100	399	6	77	13	7	14
13	100	399	4	34	35	36	
14	100	399	19	53	4		
15	100	399	15	52	53	23	24
16	100	399	57	109	23	24	112
17	100	399	57	109	23	24	112
18	100	399	57	109	23	24	112
19	100	399	57	109	23	24	112
20	100	399	57	109	23	24	112
21	100	399	57	109	23	24	112
22	100	399	57	109	23	24	112
23	100	399	57	109	23	24	112
24	100	399	57	109	23	24	112
25	100	399	57	109	23	24	112
26	100	399	57	109	23	24	112
27	100	399	57	109	23	24	112
28	100	399	57	109	23	24	112
29	100	399	57	109	23	24	112
30	100	399	57	109	23	24	112
31	100	399	57	109	23	24	112
32	100	399	57	109	23	24	112
33	100	399	57	109	23	24	112
34	100	399	57	109	23	24	112
35	100	399	57	109	23	24	112
36	100	399	57	109	23	24	112
37	100	399	57	109	23	24	112
38	100	399	57	109	23	24	112
39	100	399	57	109	23	24	112
40	100	399	57	109	23	24	112
41	100	399	57	109	23	24	112
42	100	399	57	109	23	24	112
43	100	399	57	109	23	24	112
44	100	399	57	109	23	24	112
45	100	399	57	109	23	24	112
46	100	399	57	109	23	24	112
47	100	399	57	109	23	24	112
48	100	399	57	109	23	24	112
49	100	399	57	109	23	24	112
50	100	399	57	109	23	24	112
51	100	399	57	109	23	24	112
52	100	399	57	109	23	24	112
53	100	399	57	109	23	24	112
54	100	399	57	109	23	24	112
55	100	399	57	109	23	24	112
56	100	399	57	109	23	24	112
57	100	399	57	109	23	24	112
58	100	399	57	109	23	24	112
59	100	399	57	109	23	24	112
60	100	399	57	109	23	24	112
61	100	399	57	109	23	24	112
62	100	399	57	109	23	24	112
6							

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